GUIDEBOOK TO CONSTRUCTING

INEXPENSIVE SCIENCE TEACHING EQUIPMENT

Volume III: Physics

Inexpensive Science Teaching Equipment Project

Science Teaching Center

University of Maryland, College Park

U.S.A.

Inexpensive Science Teaching Equipment Project

Science Teaching Center

University of Maryland

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CONTENTS

The Guidebook is presented in three volumes:

Volume I, Biology
Volume II, Chemistry
Volume III, Physics

The following table refers only to the contents of this volume, but the listing at the back of each volume provides an alphabetical index to all three volumes.

References within the text normally indicate the volume, chapter and number of the item referred to (e.g., CHEM/V/A3), but where a reference is to an item within the same volume, the reference indicates only the chapter and number of the item (e.g., V/A3).

Within this volume the contents of each chapter are generally presented in a logical order in which items advance from simple to complex, from a point of view of both construction and educational usage.

Table of Contents

FOREWORD

History

The Inexpensive Science Teaching Equipment Project was initiated by Dr. J. David Lockard, and got underway under his direction in the summer of 1968. Originally entitled the Study of Inexpensive Science Teaching Equipment Worldwide (IS-TEW or IS-2 Study), the Project was to (1) identify laboratory equipment considered essential for student investigations in introductory biology, chemistry and physics courses in developing countries; (2) improvise, wherever possible, equivalent inexpensive science teaching equipment; and (3) produce designs of this equipment in a Guidebook for use in developing countries. Financial support was provided by the U.S. Agency for International Development through the National Science Foundation.

The initial work of the Project was undertaken by Maria Penny and Mary Harbeck under the guidance of Dr. Lockard. Their major concern was the identification of equipment considered basic to the teaching of the sciences at an introductory level. An international survey was conducted, and a list of equipment to be made was compiled. A start was also made on the writing of guidelines (theoretical designs) for the construction of equipment.

Work on the development of the Guidebook itself got underway in 1970, with the arrival of Reginald F. Melton to coordinate the work. Over 200 guidelines were completed during the year by Donald Urbancic (Biology), Chada Samba Siva Rao and John Delaini (Chemistry), and Reginald Melton (Physics). Full use was made of project materials from around the world which were available in the files of the International Clearinghouse'on Science and Mathematics Curricular Developments, which is located in the Science Teaching Center of the University of Maryland. The guidelines were compiled into a draft edition of the Guidebook which was circulated in September, 1971, to some 80 science educators around the world for their comments and advice.

The work of constructing and developing equipment from the guidelines, with the subsequent production of detailed designs, began in a limited way in 1970, the major input at that time being in the field of chemistry by Chada Samba Siva Rao, who was with the project for an intensive two-month period. However, the main work of developing detailed designs from the guidelines was undertaken between 1971 and 1972 by John Delaini (Biology), Ruth Ann Butler (Chemistry) and Reginald Melton (Physics). Technical assistance was given by student helpers, with a special contribution from David Clark, who was with the project for a period of 18 months.

Thanks are due to those graduates, particularly Samuel Genova, Melvin Soboleski and Irven Spear, who undertook the development of specific items of equipment while studying at the Center on an Academic Year Institute program; to student helpers, especially Don Kallgren, Frank Cathell and Theodore Mannekin, who constructed the equipment; and to Dolores Aluise and Gail Kuehnle who typed the manuscripts.

Last, but not least, special acknowledgement is due to those individuals, and organizations, around the world who responded so willingly to the questionnaires in 1968 and to the draft edition of the Guidebook in 1971.

The Guidebook

The designs presented in the Guidebook are based on the premise that many students and teachers in developing countries will wish to make equipment for themselves. This does not mean that students and teachers are expected to produce all their own apparatus requirements. It is recognized that teachers have specific curricula to follow, and that "class hours" available for such work are very limited. It is also recognized that teachers, particularly those in developing countries, are not well paid, and often augment their salaries with supporting jobs, thus placing severe limits on the "out-of-class hours' that are available for apparatus production.

However, in designing equipment for production by students and teachers, two factors have been kept in mind. One, project work in apparatus development can be extremely rewarding for students, bringing both students and teachers into close contact with the realities of science, and relating science and technology in the simplest of ways. Two, it is not difficult for cottage (or small scale) industries to adapt these designs to their own requirements. The Guidebook should therefore not only be of value to students and teachers, but also to cottage industries which may well be the major producers of equipment for schools.

Although all the designs in the Guidebook have been tested under laboratory conditions in the University of Maryland, they have not been tested in school situations nor produced and tested under local conditions in developing countries. It is therefore recommended that the designs should be treated primarily as limited resource materials to be subjected to trial and feedback. It is suggested that the first time that an item is constructed it should be made precisely as described in the Guidebook, since variations in the materials, or the dimensions of the materials, could alter the characteristics of the apparatus. However, once this item has been tested the producer is encouraged to make any number of modifications in the design, evaluating the new products against the original.

Before producing new equipment in quantity, it is recommended that educators with experience in the field of science education should be involved in determining how best to make use of the Guidebook. They will wish to relate the apparatus to their own curriculum requirements, and, where necessary, prepare relevant descriptions of experiments which they recommend should be undertaken using the selected apparatus. They will want to subject the experiments and related equipment to trials in school situations. Only then will they consider large-scale production of apparatus from the designs in the Guidebook. At this stage educators will wish to control the quality of apparatus production, to train teachers to make the best use of the new apparatus, and to insure that adequate laboratory conditions are developed to permit full utilization of the apparatus. Too often in the past apparatus has sat unused on many a classroom shelf, simply because the teacher has been untrained in its usage, or the laboratory facilities have been inadequate, or because the apparatus available did not appear to fit the requirements of the existing curriculum. Such factors are best controlled by educators in the field of science education in each country. Clearly the science educator has a crucial role to play.

Apparatus development, like any aspect of curriculum development, should be considered as a never ending process. This Guidebook is not presented as a finished product, but as a part of this continuing process. There is no doubt that the designs in this book could usefully be extended, descriptions of experiments utilizing the apparatus could be added, and the designs themselves could be improved. No extravagant claims are made concerning the Guidebook. It is simply hoped that it will contribute to the continuing process of development.

TOOLS AND RAW MATERIALS

The raw materials required to make specific items of equipment are indicated at the beginning of each item description. However, there are certain tools and materials which are useful in any equipment construction workshop, and these are listed below.

Tools

Chisels, Wood

3, 6, 12, 24 mm
(i.e., 1/8", 1/4", 1/2", 1")

Cutters

Bench Shears: 3 mm (1/8")
Glass Cutter
knife
Razor Blades
Scissors: 200 mm (8")
Snips (Tinmans), Straight: 200 mm (8")
Snips (Tinmans), Curved: 200 mm (*")
Taps and Dies: 3 to 12 mm (1/8" to 1/2") set

Drills and Borers

Cork Borer Set
Countersink, 90°
Metal Drill Holder (Electrically Driven), Capacity 6 mm (1/4")
Metal Drills: 0.5, 1, 2, 3, 4, 5, 6, 7 mm
(i.e., 1/32", 1/16", 3/32", 1/8", 5/32", 3/16", 7/32", 1/4") set
Wood Brace with Ratchet: 250 mm (10")
Wood Augur, Bits: 6, 12, 18, 24 mm
(i.e., 1/4", 1/2", 3/4", 1')

Files, Double Cut

Flat: 100 mm, 200 mm (4" 8")
Round: 100 mm, 200 mm (4', *")
Triangular: 100 mm (4")

Hammers

Ball Pein: 125, 250, (1/4, 1/2 lb)
Claw 250 g (1/2 lb)

Measuring Aids

Caliper, Inside
Caliper, Outside
Caliper, Vernier (may replace above two items)
Dividers: 150 mm (6"), Toolmakers
Meter, Electrical (Multipurpose - volts, ohms, amps, etc.)
Meter Stick
Protractor
Scriber

Measuring Aids (Continued)

Set Square
Square, Carpenter's: 300 mm (12") blade
Spoke Shave: 18 mm (3/4")
Wood Smoothing Plane

Pliers

Combination: 150 mm(6")
Needle Nose: 150 mm (6")
Side Cutting: 150 mm (6")
Vise Grips

Saws, Metal

300 mm (.2") blades

Saws, Wood

Back Saw: 200, 300 mm (8", 12")
Coping Saw: 200 mm (8")
Cross Cut: 600 mm (24")
Hand Rip: 600 mm (24")
Key Hole Saw: 200 mm (8")

Screw Drivers

100 mm (4") with 2 and 3 mm tips
150 mm (6"), with 5 mm tip
200 mm (8"), with 7 mm tip

Vises

Metal Bench Vise: 75 mm (3")
Wood Bench Vise: 150 mm (6")

Miscellaneous

Asbestos Pads
Goggles, Glass
Oil Can: 1/2 liter (1 pint)
Oil Stone, Double Faced
Punch, Center
Sandpaper and Carborundum Paper, Assorted grades
Soldering Iron: 60 watts, 100 watts

Raw Materials

Adhesives

All Purpose Cement (Elmers, Duco)
Epoxy Resin & Hardener (Araldite)
Rubber Cement (Rugy)
Wood Glue (Weldwood)
Cellophane Tape
Plastic Tape
Masking Tape

Electrical Materials

Bulbs with Holders: 1.2, 2.5, 6.2 volts
Dry Cells: 1.5, 6 volts
Electrical Wire: Cotton or Plastic covered
Fuse Wire: Assorted
Lamps: 50, 75, 100 watts
*Magnet Wire: #20, 22, 24, 26, 28, 30, 32, 34
Nichrome Wire: Assorted
Parallel Electrical Cording
Plugs
Switches

Glass and Plastic

Acrylic (Plastic) Sheets: 2 cm and 2.5 cm thick
Plates, Glass
Tubes, Glass: 3, 6 mm (1/8", 1/4") internal diameter

Hardware

8olts and Nuts, Brass or Steel; 3 mm (1/8") diameter: 12, 24, 48 mm (1/2", 1", 2") lengths
Nails 12, 24mm (1/2", 1") lengths
Screws, Eye
Screws, Wood: 12, 18, 24, 26 mm (1/2", 3/4, 1", 1 1/2")
Thumbtacks
Washers (Brass and Steel): 6, 9 mm (1/4", 5/16") diameter
Wingnuts (Steel): 5 mm (3/16")

Lumber

Boxwood (Packing Case Material)
Hardboard: 6 mm (1/4") thick
Kiln Dried Wood: 2.5 x 15 cm (1" x 6") cross section
1.2 x 15 cm (1/2" x 6") cross section
Plywood: 6, 12 mm (1/4", 1/2") thickness
Wood Dowels: 6, 12 mm (1/4", 1/2") thickness

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* U. S. Standard Plate numbers are used in this book to indicate the gauge of different wires. Where wires are referenced against other numbering systems appropriate corrections should be made in determining the gauges of materials required. The following comparison of gauges may be of interest:

Standard	Diameter of #20 Wire
Brown & Sharp	0.08118
Birmingham or Stubs	0.089
Washburn & Moen	0.0884
Imperial or British Standard	0.0914
Stubs' Steel	0.409
U. S. Standard Plate	0.09525

Metal Sheets

Aluminum: 0.2, 0.4 mm (l/100", 1/64") thickness.
Brass: 0.4, 0.8 mm (1/64", 1/32") thickness.
Galvanized Iron: 0.4 mm (1/64") thickness.
Lead: 0.1 mm (1/250") thickness.
Spring Steel, Packing Case Bands

Metal Tubes:

Aluminum, Brass, Copper: 6, 12 mm (1/4", 1/2") internal diameter.

Metal Wires

Aluminum: 3 mm (1/8") diameter
Coathanger: 2 mm (1/16") diameter
*Copper: #20, 24
Galvanized Iron: 2 mm (1/16") diameter
*Steel: #20, 26, 30.

Paint Materials

Paint Brushes
Paint Thinner
Varnish
Wood Filler

Miscellaneous

Aluminum Foil
Cardboard Sheeting
Containers (Plastic or Glass)
Corks (Rubber or Cork)

Hinges: Assorted
Machine Oil
Marbles
Mesh (Cotton, Nylon, Wire)
Modelling Clay (Plasticene)
Paper Clips
Pens: Felt (Marking Pens)
Pins and Needles
Rubber Bands
Soldering Lead
Soldering Paste
Spools
Steel Wool
Straws
String (Cord,.Cotton, Nylon)
Styrofoam
Syringes: Assorted
Wax (Paraffin)

*See footnote on previous page.

I. BALANCES

The balances presented have been divided into three categories:

A. ELEMENTARY BALANCES

These are relatively crude, but extremely easy to make, even for elementary students, and serve as an excellent introduction to an understanding of balances.

B. EXPERIMENTAL BALANCES

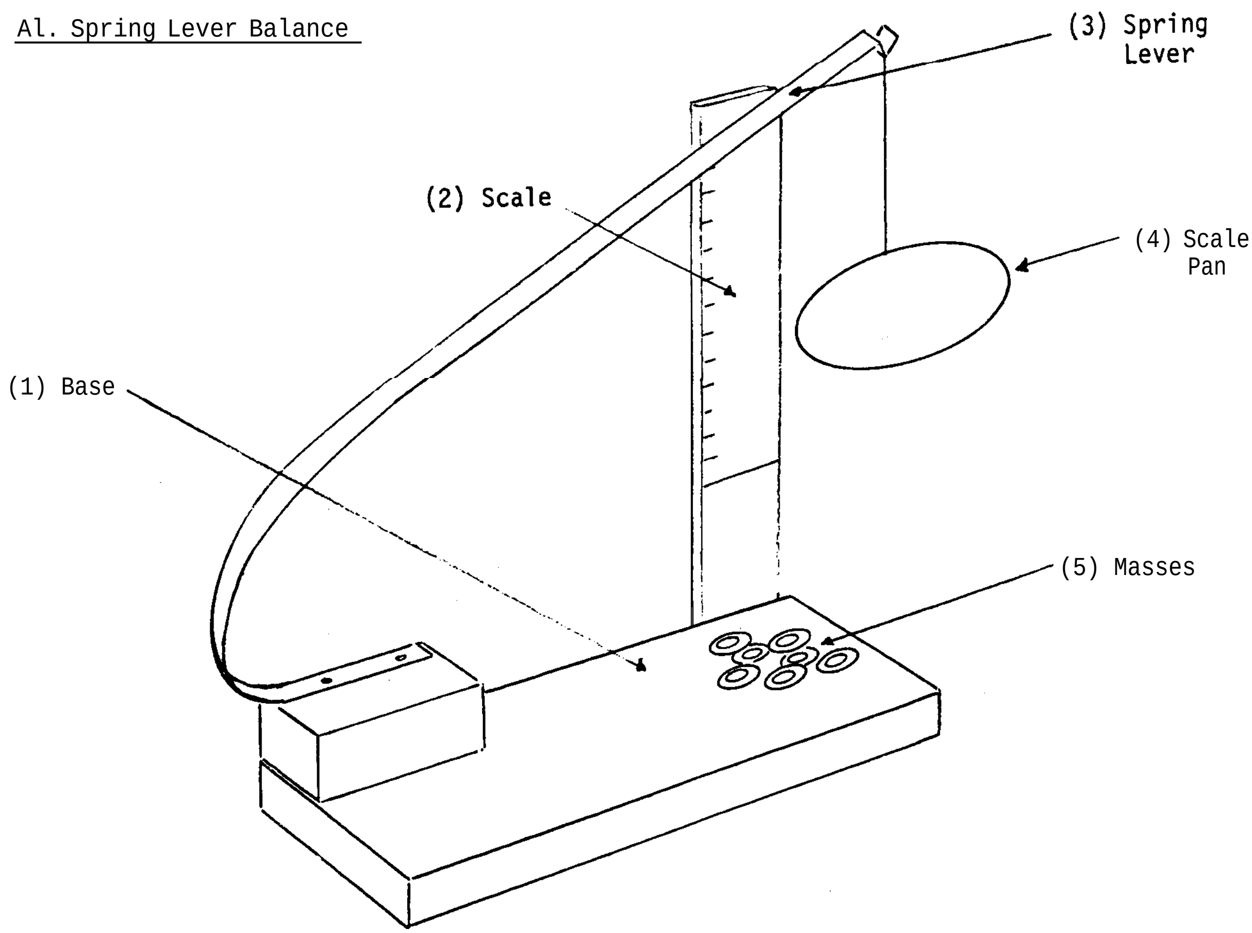
These are somewhat more exact and are useful for undertaking investigations into the properties of balance.

C. FUNCTIONAL BALANCES

These are relatively sophisticated and designed primarily for functional usage.

A. ELEMENTARY BALANCES

Al. Spring Lever Balance



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	13 cm x 6 cm x 1.5 cm
	1	Wood (B)	5 cm x 2.5 cm x 2.5 cm
(2)Scale	1	Wooden Strip (C)	20 cm x 2 cm x 0.5 cm
	1	White Paper (D)	15 cm x 2 cm
(3) Spring Lever	1	Packing Case Steel Band (E)	30 cm x 1.2 cm x 0.02 cm
(4) Scale Pan	1	Galvanized Iron Wire (F)	50 cm length, #24
	1	Aluminum Sheet (G)	5.5 cm x 5.5 cm x 0.02 cm approximately
(5)Masses	---	Washers (H)	--

b. Construction

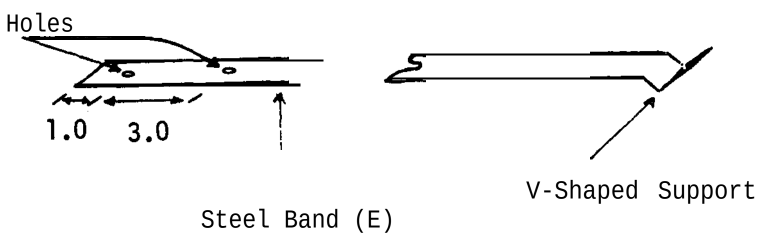
1) Base

Attach wood (B) to one corner of wood (A) to support the spring lever above the base.

(2) Scale

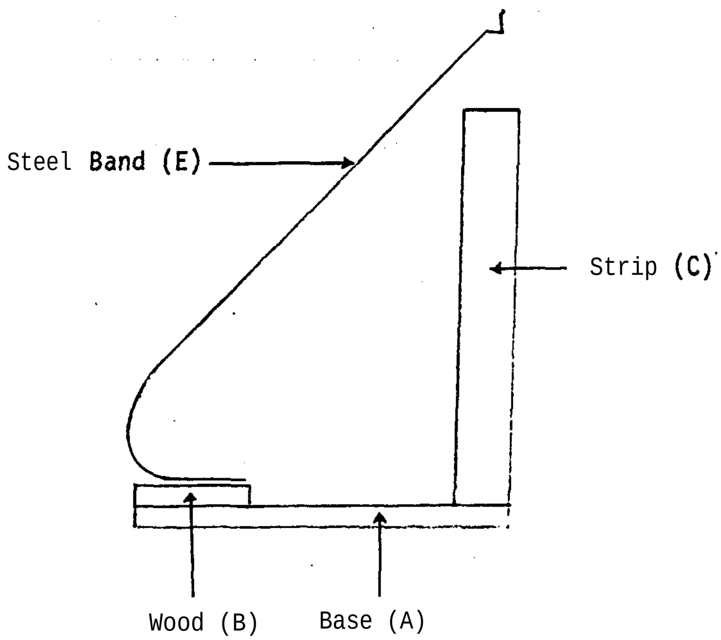
Attach strip (C) vertically to the adjacent corner of the base, Glue a strip of white paper (D) to the top front surface of strip (C) to serve as a scale.

(3) Spring Lever



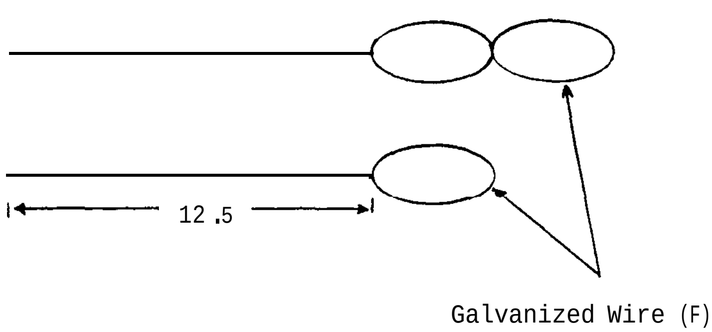
Take packing case steel band (E) and make a small V-shape at one end to hold the scale pan support wire. Drill two holes in the other end to take two small nails.

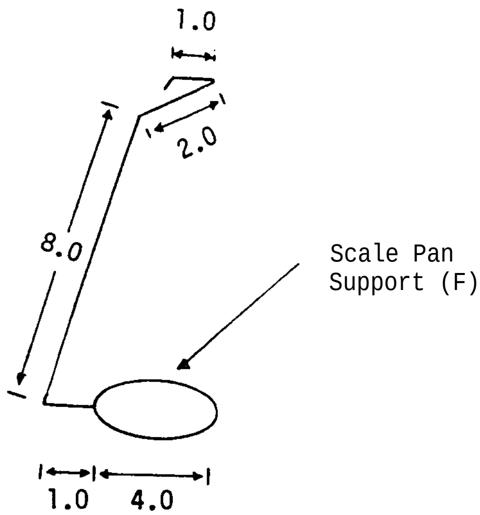
Attach the drilled end of band (E) to the top of block (B) on the base with two small nails. Bend the band smoothly over to form an elongated C-shape as indicated.



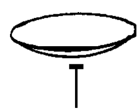
(4) Scale Pan

Take the galvanized iron wire (F) and make it into a double strand 25 cm long. Use half of the new length to form a "figure 8" in the wire.





Fold one loop on top of the other, and then bend the remaining straight portion of the wire to the shape indicated. You now have a scale pan support which may be attached to the spring lever.



Pan (G)

Make the pan itself from the aluminum sheet (G). Hammer it at the center to create a saucer shaped pan. Sit the pan on the loop of the scale pan support.

(5) Masses

Such items as nails, washers and paper clips may be used for masses,

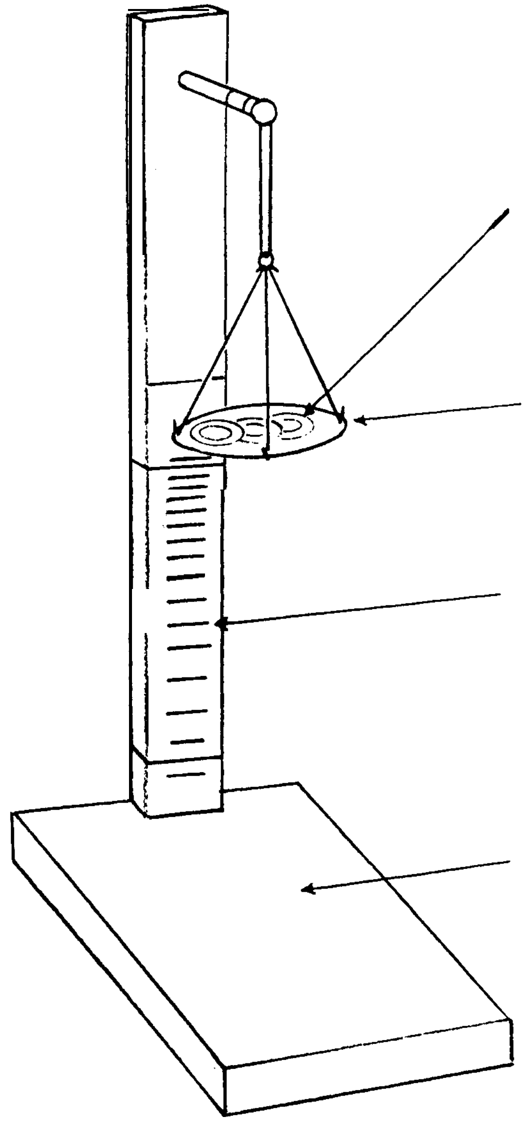
C. Notes

(i) Note the point of intersection between the spring lever and the left side of the scale, and record the position with a temporary zero mark. Determine the elastic limit of the spring lever by adding successively larger masses to the scale pan, and noting on each occasion whether the spring returned to the same zero point on removing the masses from the pan. In this particular case it was noted that the elastic limit was reached with a mass of 33 g.

(ii) Note the new zero point on the scale with a permanent mark. This will be slightly below the temporary mark due to the spring being subjected to a force which extended it slightly beyond its elastic limit. Now add masses 1 g at a time calibrating the scale accordingly up to 20 g.

(iii) A more sensitive balance, weighing from 0 to 10 g, may be made in an identical fashion by using half the width of packing case band as the spring lever, Such a balance made here was found to have an elastic limit of 27 g, and was readily calibrated as described above.

A2. Rubber Band Balance



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	15 cm x 10 cm x 1.5 cm
(2) Support	1	Wood Strip (B)	45 cm x 4 cm x 2 cm
	2	Screws (C)	2.5 cm long
	1	White Paper (D)	30 cm x 4 cm
	2	Rubber Bands (E)	--

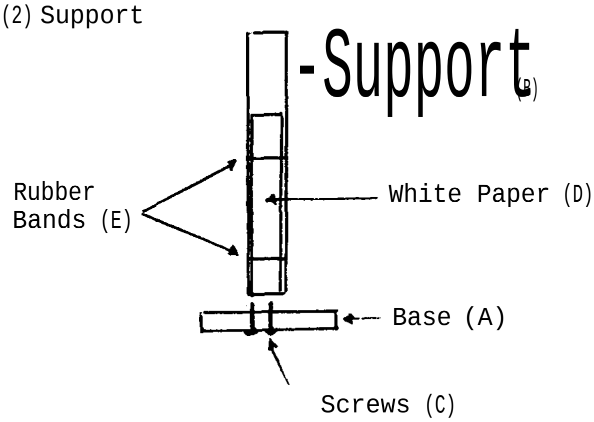
(3) Scale Pan Unit	1	Nail (F)	7 cm long approximately
	1	Rubber Band (G)	--
	1	Galvanized Wire (H)	#20, 3 cm long
	1	Aluminum Sheet (I)	6 cm x 6 cm x 0.02 cm
	3	Wire (J)	#24, 9 cm long
	1	Adhesive Tape (K)	10 cm x 1 cm
(4) Masses	--	Washers	--

b. Construction

(1) Base

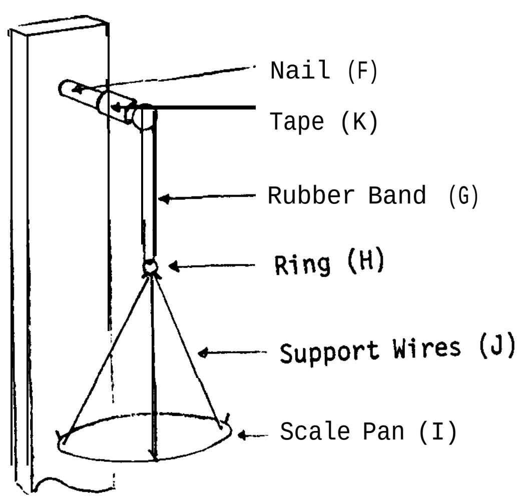
Use wood (A) to serve as the base.

(2) Support



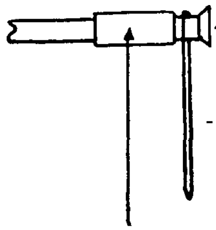
Attach wood strip (B) vertically to the base with two screws (C). Attach the plain white paper (D) to the front of the vertical support (B) with rubber bands (E).

(3) Scale Pan Unit



Drive nail (F) horizontally into top of the vertical support, and suspend a rubber band (G) from its end. Take the galvanized wire (H) and bend it into the shape of a ring which can be suspended from the rubber band.

Hammer the aluminum sheet (I) at its center so as to create a saucer shape, thus producing a reasonable scale pan. Use a hammer and nail to produce three small holes near the perimeter of the pan. Suspend the pan from the ring by means of the three lengths of wire (J) bent over at both ends to form suitable hooks.



To prevent the rubber band sliding backwards and forwards on the supporting nail a length of adhesive tape (K) should be wrapped around the nail so as to leave a groove between the tape and the end of the nail, the rubber band being held in position in the groove.

(4) Masses

Such items as nails, washers and paper clips may be used as masses.

C. Notes

(i) Note the point on the scale corresponding to the position of the unloaded scale pan. Determine the elastic limit of the rubber band by loading the scale pan with increasing masses, noting In each instance whether the unloaded pan returns to the same zero point on the scale. For the particular band used in this instance the elastic limit was reached with a mass of 235 g.

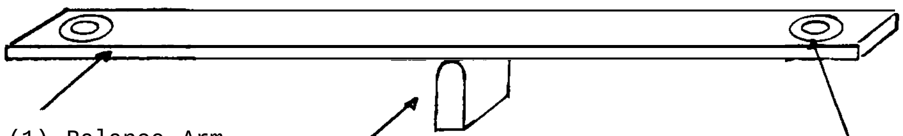
(ii) Check the zero position on the scale once more, making a permanent mark opposite the scale pan, then calibrate the scale by adding successive weights to the pan, keeping well within the elastic limits of the band.

(iii) A nonuniform scale will result.

(iv) The rubber band will deteriorate with time, and this will be particularly rapid in tropical countries. However, the band can easily be replaced and the scale recalibrated so long as the teacher has a suitable set of weights available.

(v) If the scale pan is suspended from two parallel elastic bands, instead of one, the range and the elastic limit will be increased. With two bands the elastic limit increased in this particular case to 550 g. However, it was noted that if masses of less than 500 g were left on the pan for any period of time there was still a tendency for the rubber band to be plastically deformed.

A3. Simple Beam Balance



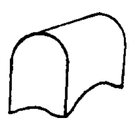
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Balance Arm	1	Meter Ruler (A)	100 cm long
(2) Pivot	1	Wood (B)	4 cm x 4 cm x 2 cm
(3) Masses	--	Washers (D)	--

b. Construction

(1) Balance Arm — Use the meter ruler (A) as a balance arm.

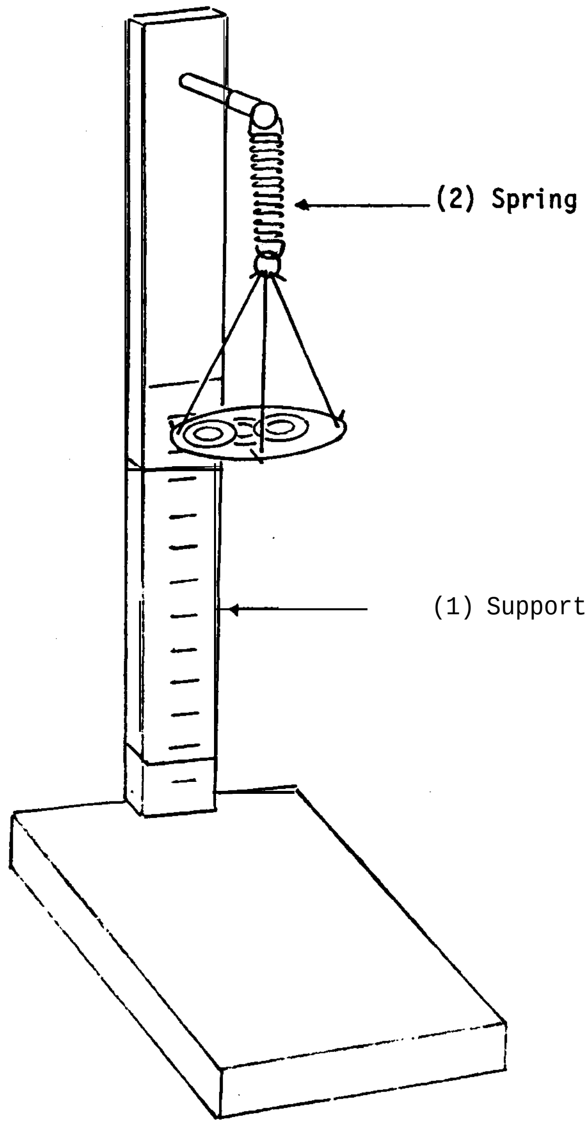
(2) Pivot — Round off one end of the available piece of wood (B) with sandpaper.



(3) Masses — Use washers or heavy nuts (D) for masses.

B. EXPERIMENTAL BALANCES

Bl. Extending Spri nq Balance



a. Materials Required

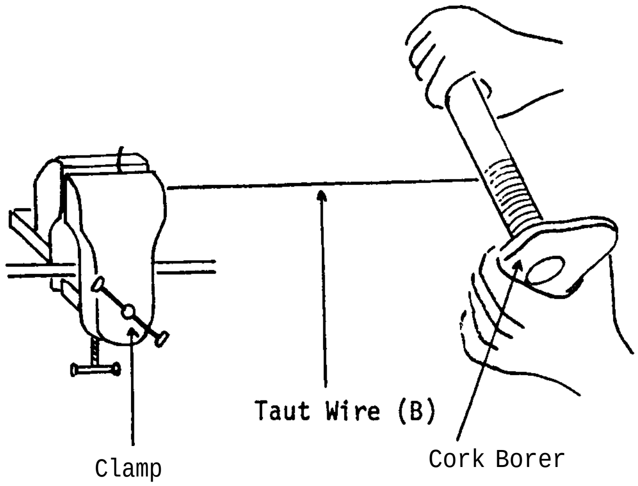
Components	Qu	Items Required	Dimensions
(1) Support	1	Rubber Band Balance (A)	I/A2
(2) Spring	1	Steel Wire (B)	0.09 cm diameter, 225 cm long

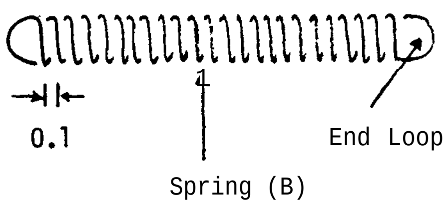
b. Construction

(1) Support

Make the support (A) in precisely the same way as the rubber band balance described under I/A2,

(2) Spring





Take a length of steel wire (B) (e.g. piano wire) and fasten one end firmly in a clamp. Attach the other end to a cork borer or similar device (see notes). If the diameter of the axis of the cork borer used is 1.4 cm, the diameter of the resultant spring (when released) will approach 2 cm. Keeping the wire under tension wind some 30 turns of wire into the spring, each turn being separated from the next by about 0.1 cm. Use pliers to twist a loop in each end of the spring. Remove the rubber band which supports the scale pan in the rubber band balance (A), and replace it by the steel spring.

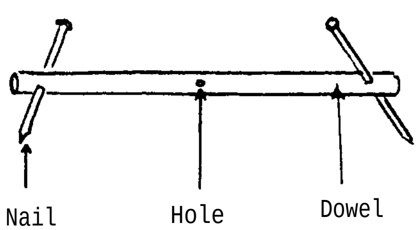
c. Notes

(i) Determine the elastic limit of the steel spring, and calibrate the balance in exactly the same way as for the rubber band balance.

(ii) With the materials described above the spring was extended until the scale pan touched the base of the apparatus without reaching the elastic limit of the spring. The scale was calibrated from 0 to 400 g (an extension of 19.6 cm), and it was noted that the resultant scale was uniform.

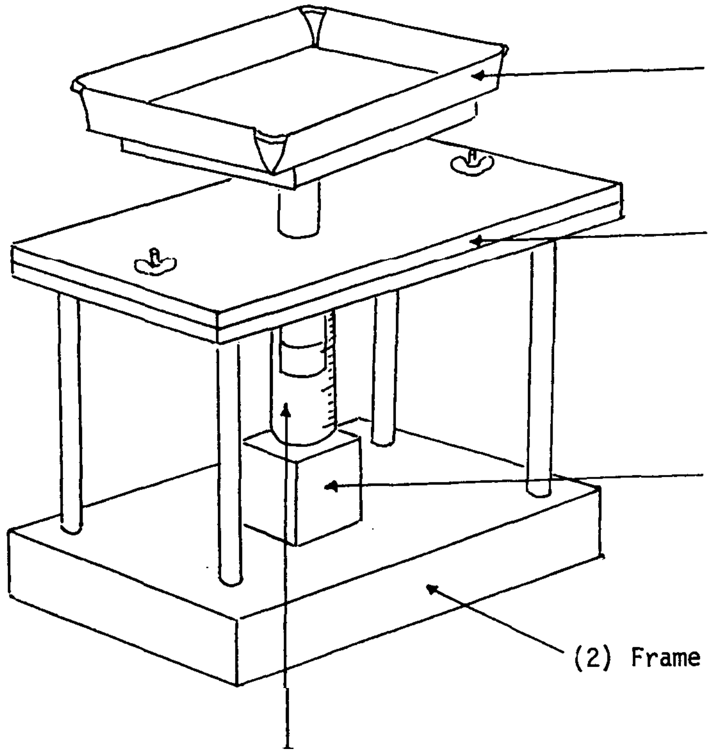
(iii) A more sensitive, or weaker, spring may be made by using thinner wire or by making the diameter of the spring greater,

(iv) A very convenient winding device for the spring is a wooden dowel (in this case 1.4 cm diameter, 30 cm long) with a hole (0.6 cm diameter) drilled at either end to take a nail about 10 cm long.



A small hole (diameter 0.2 cm) drilled through the center of the dowel holds the wire, and the latter may be wound into a spring in much the same way as with the help of the cork borer, in this case winding the wire spring onto the wooden dowel which is turned with the help of the protruding nails.

B2. Compression Spring Balance



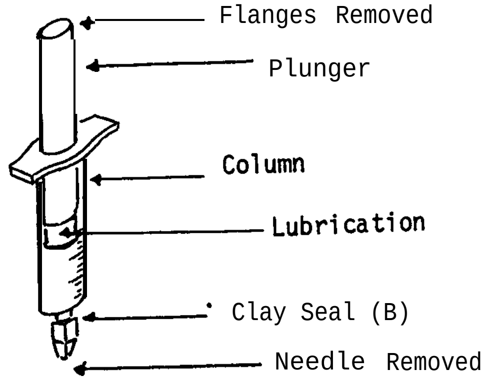
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Syringe (A)	Column length approximately 6.4 cm, internal diameter approximately 1.3 cm
	--	Modelling Clay (B)	--
(2) Frame	1	Wood (C)	14 cm x 9 cm x 2 cm
	1	Wood (D)	14 cm x 9 cm x 0.7 cm
	4	Wooden Dowels (E)	12 cm long, 1 cm diameter
(3) Support Block	1	Wood (F)	2 cm x 2 cm x L cm, where L is dependent on length of syringe
(4) Upper Platform	1	Wood (G)	14 cm x 9 cm x 0.07 cm
	2	Bolts (H)	2 cm long, 0.3 cm diameter
	2	Wing Nuts (I)	0.3 cm diameter

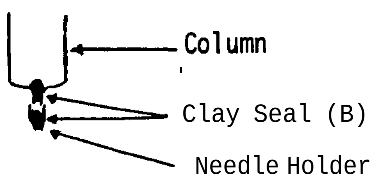
(5) Scale Pan	1	Galvanized Wire (J)	32 cm long, 0.4 cm diameter
	1	Aluminum Sheet (K)	12 cm x 12 cm x 0.05 cm
	1	Wood (L)	5 c m x 5 c m x 2 c m

b. Construction

(1) Syringe

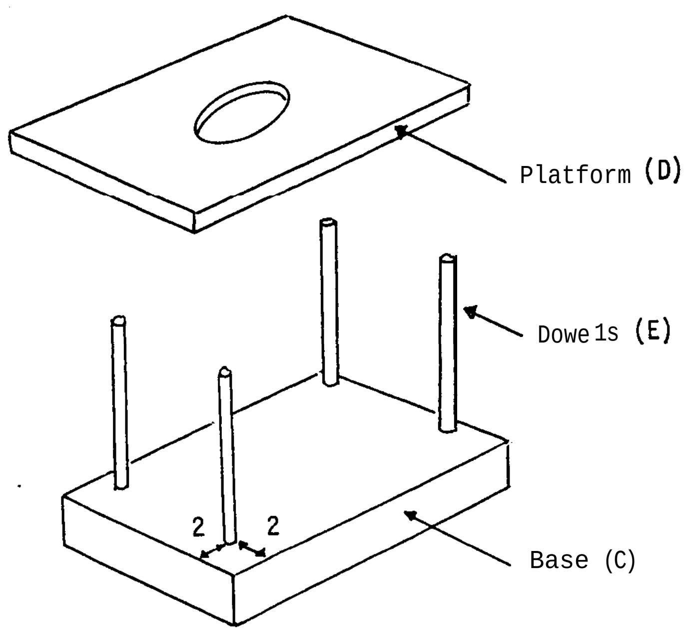


Take the disposable plastic syringe (A) and remove the needle and the top flanges. Remove the plunger from the column, and smear the end of the plunger with petroleum jelly thus insuring a well lubricated plunger, and a good airtight seal.



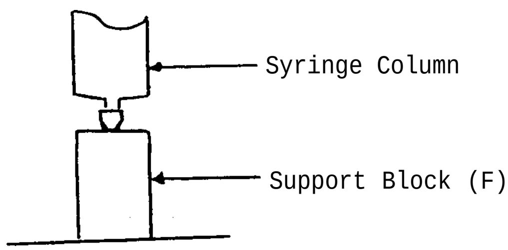
Insert the plunger about 1 cm into the column, and then seal off the open end of the column with modelling clay with the help of the metal needle holder.

(2) Frame



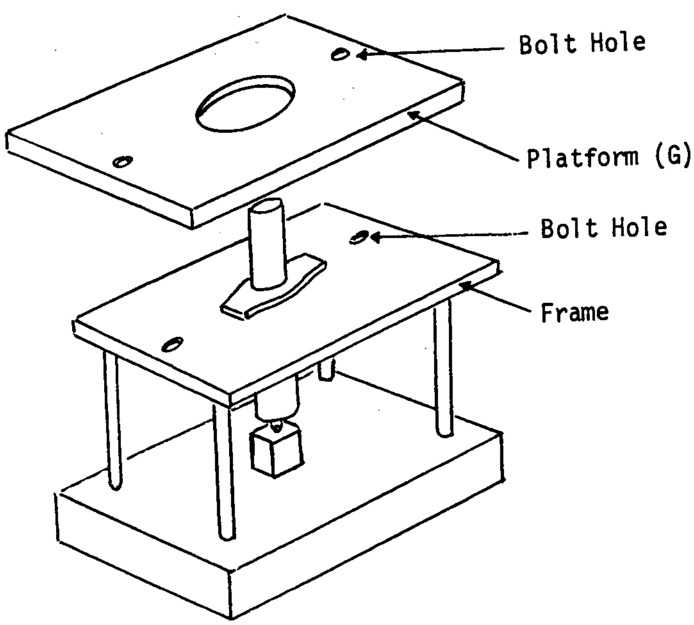
Make the base of the frame from wood (C) drilling holes (1 cm diameter) at the corners to take the dowels (E). Use wood (D) as a platform, drilling holes (1 cm diameter) at each corner to take the dowels. Attach the base and platform together by means of the four dowels,fixing the latter firmly in position with wood cement. Drill a hole (1.4 cm diameter) through the middle of the platform, making it just large enough to take the plunger.

(3) Support Block



Insert the syringe column through the hole in the platform. It will hang suspended with a gap between the bottom of the syringe and the surface of the base. Cut a small support block (F) to fill this gap, and drill a small inset into the top of the block to hold the syringe firmly in position. (The block will also prevent the modelling clay seal in the bottom of the syringe being readily broken under pressure). Fasten the support block to the base with wood cement.

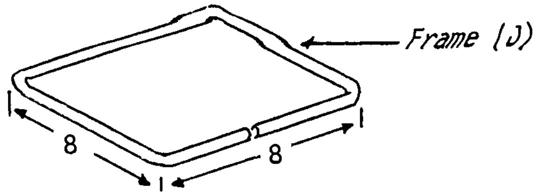
(4) Upper Platform



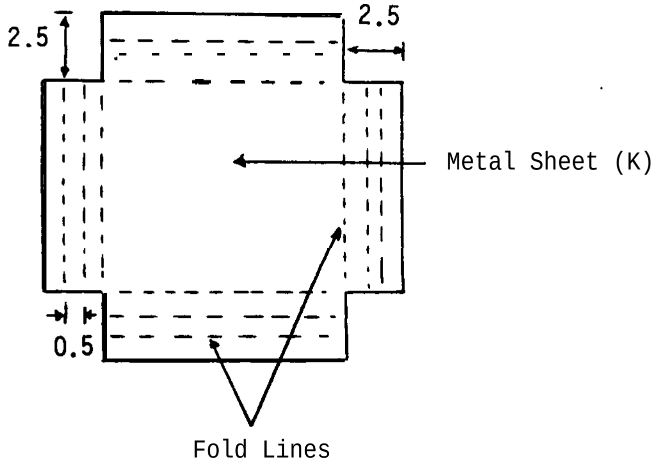
Make the upper platform from wood (G) to fit on top of the existing platform for the frame.

Drill a hole (diameter the same as that of the syringe plunger) in the middle of the upper platform, and slide the latter into position on the frame. Drill two bolt holes (0.3 cm diameter) through both platforms, and fasten them together by means of bolts (H) and wing nuts (I), thus holding the syringe firmly in position.

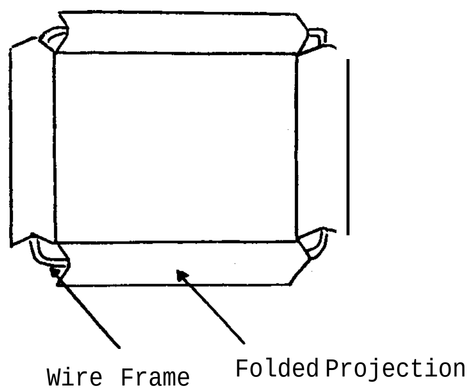
(5) Scale Pan

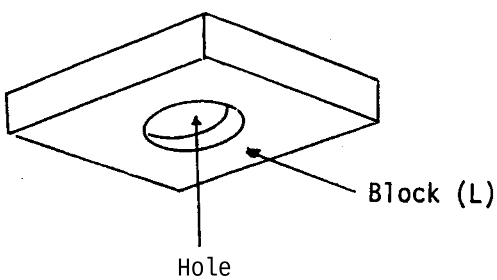


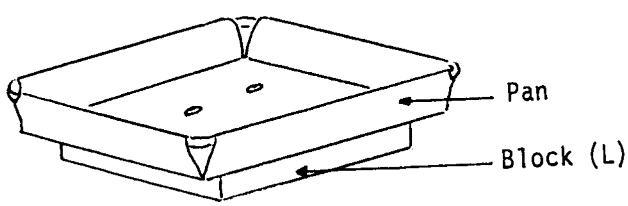
Make a frame for the scale pan out of aluminum or galvanized *wire (J).*



Cut the corners (2.5 cm x 2.5 cm) out of the aluminum sheet (K), and fold the projections as illustrated so that they may be bent over the wire frame to form a suitable scale pan.





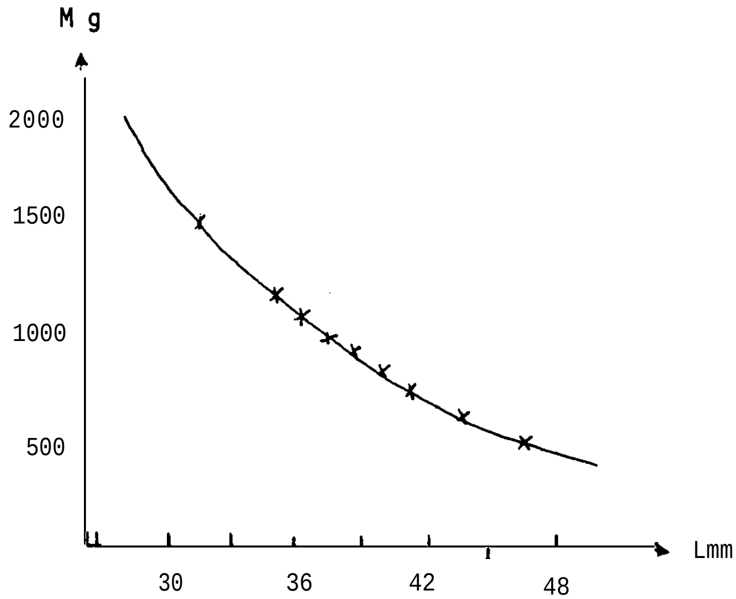


Take the wooden block (L), and drill a hole (the same diameter as the plunger, and 1.5 cm deep) into the middle of the block. Nail the scale pan squarely on to the undrilled surface of the block. Line the inside of the hole in the lower surface with wood filler. Lower the block onto the plunger. The latter will be held firmly within the hole once the wood filler dries.

c. Notes

(i) The balance may readily be calibrated with known weights by noting the length of the trapped air column for each given mass in the scale pan.

(ii) The variation of length of the air column with mass is not linear, as can be seen from the plot below showing the relationship of air column length (L) to the applied mass (M).

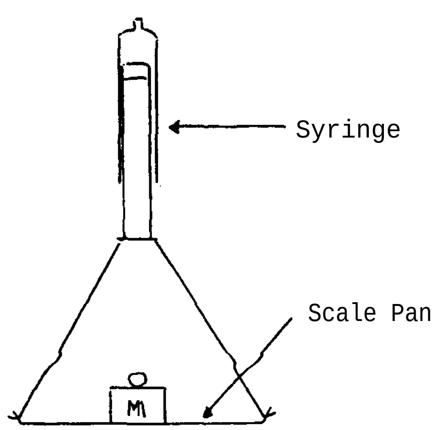


M g	L = mm
500	47.8
600	44.8
700	42.4
800	41.2
900	40.0
1000	38.8
1100	37.6
1200	36.4
1500	32.8
2000	28.0

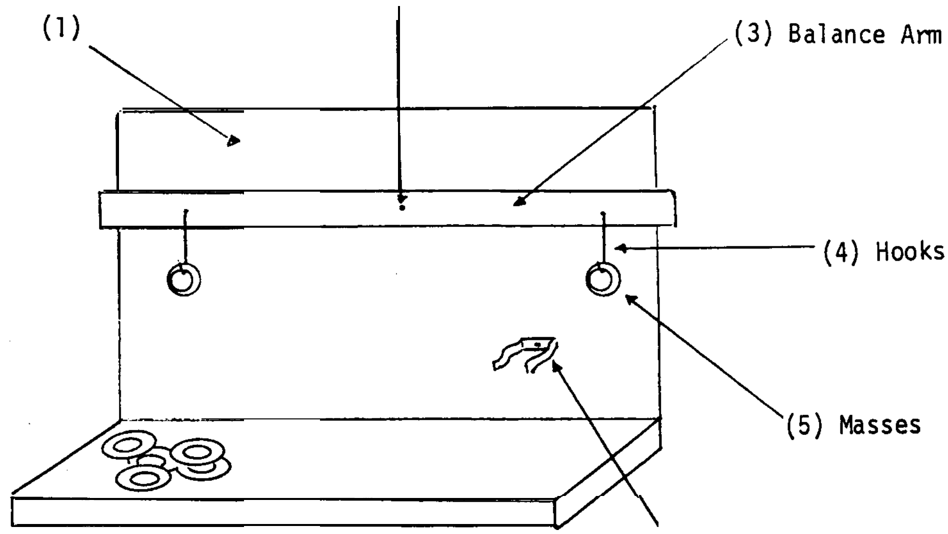
(iii) Because of friction between the plunger and the sides of the column, the syringe tends to be insensitive to weights of less than about 500 g, but it readily measures weights from this lower limit up to around 5,000 g.

(iv) The sensitivity of the balance appears to increase as the length and diameter of the syringe column increases.

(v) In designing new balances it would be of particular interest to consider the use of a syringe as an extension spring, as illustrated in the diagram. It would appear that this balance might have quite a different range and sensitivity from that of the compression spring balance.



B3. Pegboard Balance



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support Stand	1	Wood (A)	50 cm x 10 cm x 2 cm
	1	Pegboard (B)	50 cm x 35 cm x 0.3 cm
(2) Pivot	1	Wood (C)	8 cm x 3 cm x 1 cm
	1	Nail (D)	5 cm long, 0.3 cm diameter
	2	Bolts (E)	2 cm long, 0.3 cm diameter
	2	Wing Nuts (F)	0.3 cm internal diameter
(3) Balance Arm	1	Wood (G)	50 cm x 2.5 cm x 0.5 cm
	1	Aluminum Sheet (H)	2.5 cm x 2.0 cm x 0.02 cm
(4) Hooks	6	Paper Clips (I)	--
(5) Masses	20	Washers (J)	--
(6) Spring Clips	2	Packing Case Steel Bands (K)	8.5 cm x 1 cm x 0.02 cm
	2	Bolts (L)	1.5 cm long, 0.3 cm diameter
	2	Wing Nuts (M)	0.3 cm internal diameter

b. Construction

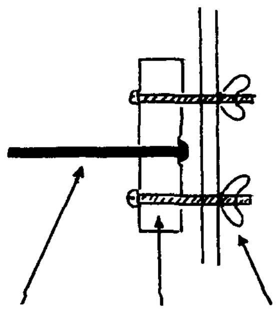
(1) Support Stand

Attach the sheet of pegboard (B) vertically on to wood (A) to make the support.

(2) Pivot

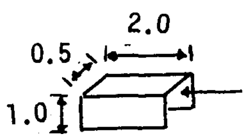
Orill a small hole (diameter 0.2 cm) through wood (C), and make a small inset over the hole. Drive nail (D) through the hole so that the nail head sits in the inset.

Drill two more holes (diameter 0.3 cm) through the wood, close to the edges, and use bolts (E) and wing nuts (F) to attach the block to the pegboard support stand. The newly attached pivot nail should be at the center of the pegboard and about 20 cm above the base.



(3) Balance Ann

Make the balance arm out of wood (G). Drill holes (0.5 cm diameter) at regular intervals in the arm as illustrated, and balance the arm as required on the nail pivot. Take a sheet of aluminum (H) and bend it into a counterbalance. Set.it in an appropriate position on the balance arm to correct any irregularity in the balance of the latter.



0.5 .25

0.5

Counterbalance (H)

Balance Arm (G)

(4) Hooks

Make each hook by straightening out a paper clip (I), and cutting off a length of about 6 cm. Then bend the wire into the shape shown. Make six such hooks.

1

4.0

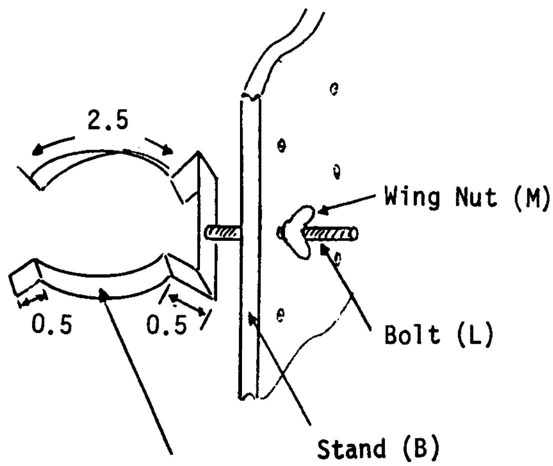
?

Hook (I)

(5)Masses

Use heavy washers (J) or nuts for masses.

(6) Spring Clips

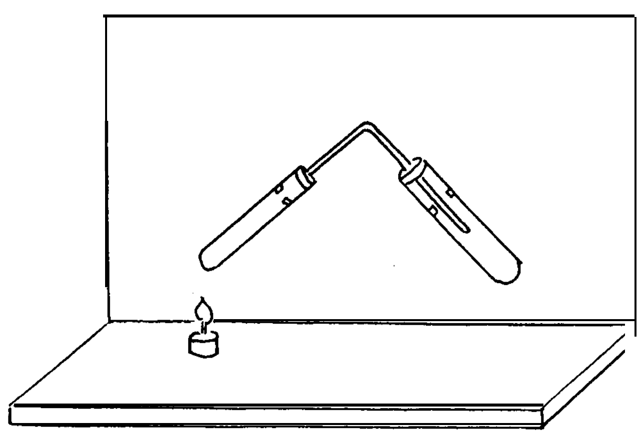


Take a length of packing case steel band (K) and drill a hole (diameter 0.3 cm) through its center. Then bend it as indicated into the form of a spring clip. This size of spring clip is suitable for a standard test tube. Attach this to the support stand with a bolt (L) and wing nut (M). Two identical spring clips should be made.

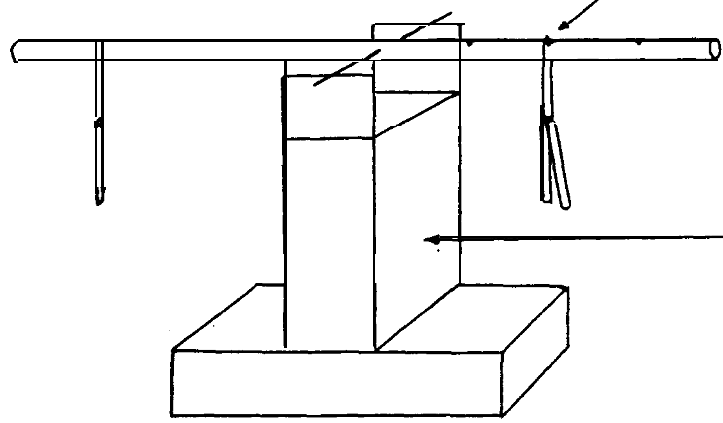
C. Notes

(i) The position of the pivot in the horizontal lever can be changed at will not only from one end of the lever to the other, but also from the lower edge of the lever to the upper edge (changing the sensitivity of the balance). The apparatus is particularly suitable for studying "moments".

(ii) With the help of the spring clips described the apparatus may be converted into a general support stand.



B4. Soda Straw Balance

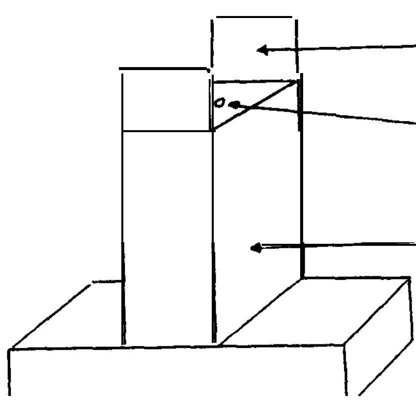


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	2	Wood (A)	6 cm x 2 cm x 2 cm
	1	Aluminum Sheet (B)	6 cm x 2 cm x 0.02 cm
(2) Balance Arm	1	Soda Straw (C)	16 cm long approximately
	1	Needle (D)	3 cm long
(3) Masses	10	Paper Clips (E)	--

b. Construction

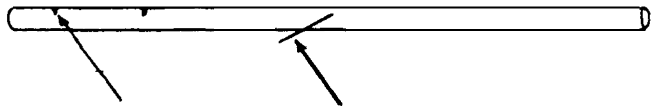
(1) Support



Screw, or nail, one block of wood (A) on to the other so as to form an inverted sheet (B) and bend this into a three sided support to sit on top of the inverted "T" support.
Drill a small hole through the base of the aluminum sheet so that the latter may be attached to the wood support by means of a nail or screw.

(2) Balance Arm

Pierce the middle of the straw (C) with needle (D) making sure that the latter is close



to the top surface of the straw, thus lending stability to the balance arm. Use a razor blade to cut small V-shaped slots in the top surface of the straw at regular intervals of 2 cm. Balance the straw on top of the support.

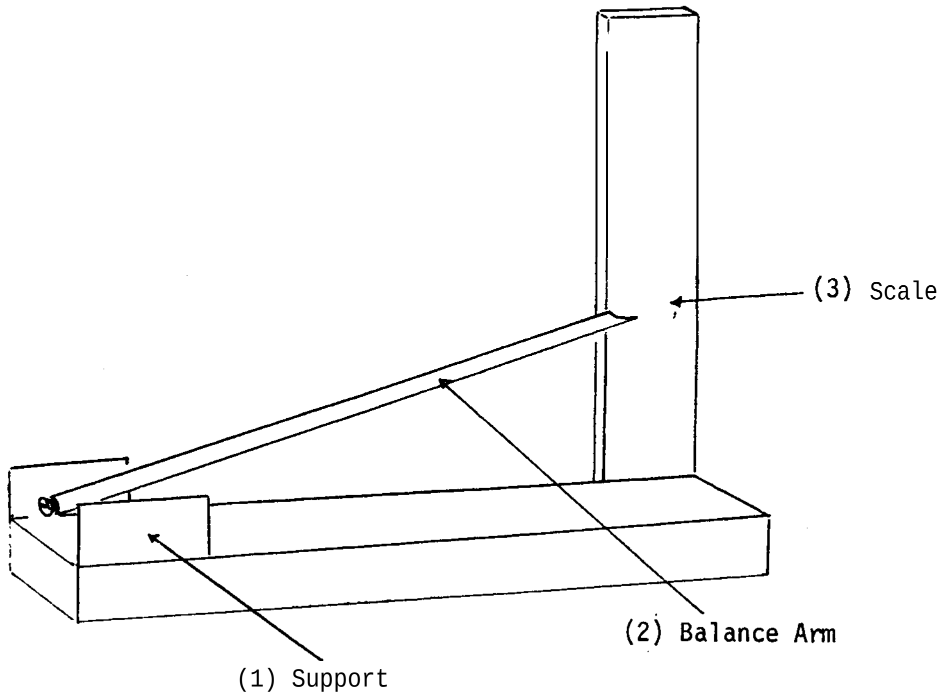
(3) Masses

Use the paper clips (E) as appropriate masses.

c. Notes

(i) This apparatus is suitable for individual student investigation of the principle of "moments".

B5. Microbalance

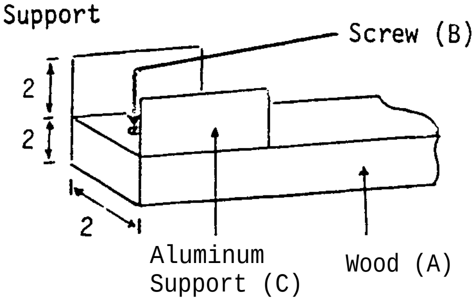


a, Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	1	Wood (A)	15 cm x 2 cm x 2 cm
	1	Screw (B)	1 cm long
	1	Aluminum Sheet (C)	6 cm x 2 cm x 0.02 cm
(2) Balance Arm	1	Straw	16 cm long approximately
	1	Bolt (E)	1 cm long approximately
	1	Needle (F)	3 an long
(3) Scale	1	Wood Strip (G)	12 cm x 2 cm x 0.4 cm
	1	White Paper (H)	10 cm x 2 cm
	2	Rubber Bands)	--

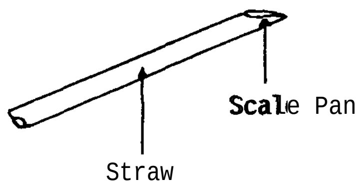
Construction

(1) Support



Bend the aluminum sheet (C) into a three sided support. Drill a hole (0.2 cm diameter) through the middle of the support base, and then attach the support to the end of wood (A) by means of a screw through the hole.

(2) Balance Arm



Take the straw (D) and select a short bolt (E) which fits tightly into the end of the straw. Screw the bolt partway into the straw. Cut the free end of the straw with a pair of scissors to make an appropriate scale pan in the balance arm, Pierce the straw near to the top surface, and sufficiently close to one end, with the needle (F) so that the latter will serve as a pivot. Balance the straw on the support. A few trials will be necessary to obtain a suitable position for the needle.

(3) Scale

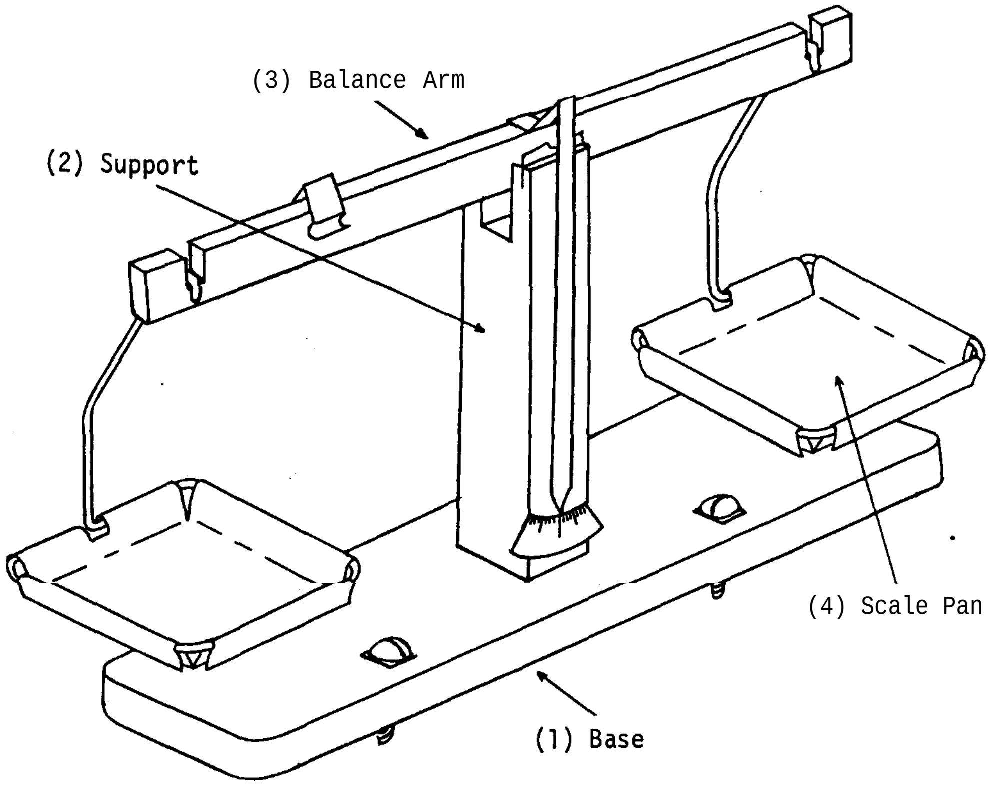
Nail the wood strip (G) vertically on to the end of the base (A), and attach the piece of white paper (H) to the front surface with rubber bands (I).

c. Notes

(i) The position of the pivot and screw should be adjusted so that the straw points toward the top of the scale. Assuming the weight of a large sheet of paper (or several sheets together) can be determined, calibration may be effected by placing a fraction of a sheet of paper (e.g. 1 square cm or less) on the soda straw scale pan, and noting the depression of the straw on the scale. This balance is sufficiently sensitive to determine the mass of extremely small bodies such as mosquitoes, strands of hair etc.

C. FUNCTIONAL BALANCES

Cl. Equal Arm Balance©



a. Materials Required

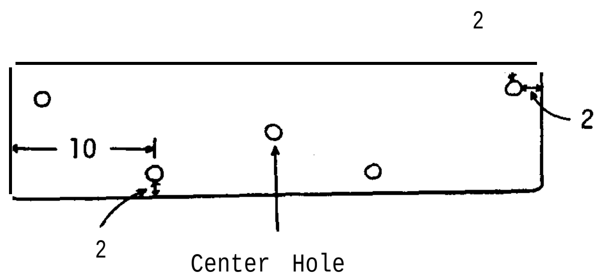
Components	Qu	Items Required	Dimensions
(1) Base	1	Softwood (A)	38 cm x 9 cm x 2 cm
	4	Bolts (B)	0.2 cm diameter, 3 cm long
	8	Nuts (C)	0.2 cm internal diameter
(2) Support	1	Screw (D)	3 cm long
	1	Wood (E)	15.5 cm x 3 cm x 2 cm
	1	Razor Blade (F) (Double Edge)	--

© From Reginald Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 5-8.

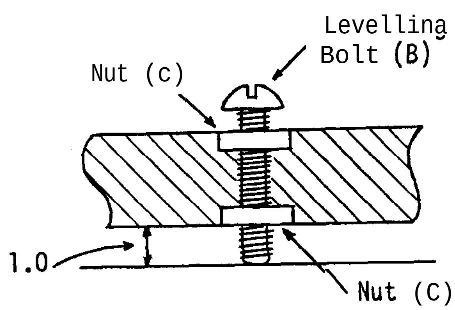
(3) Balance Arm	1	Wood (G)	38 cm x 2 cm x 0.5 cm
	1	Needle (H)	0.1 cm diameter, 5 cm long
	1	Aluminum Sheet (I)	19 cm x 0.5 cm x 0.5 cm
	1	Aluminum Sheet (J)	4 cm x 1.5 cm x 0.05 cm
(4) Scale Pans	2	Aluminum Wires (K)	50 cm long, 0.3 cm diameter
	2	Aluminum Sheets (L)	13.5 cm x 13.5 cm x 0.02 cm
	1	White Paper (M)	4 cm x 2 cm

b. Construction

(1) Base



Base (A)



Side View

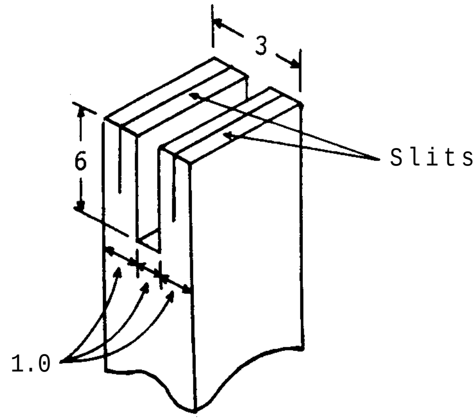
Make the base out of softwood (A). Drill four holes (diameter 0.3 cm) in the base to take the four levelling bolts (B). Inset the nuts (C) into the base above and below the holes by hammering the nuts into the wood surface. They may be fixed permanently in position with epoxy resin.

Two nuts (C) on each bolt (B) prevent the latter from wobbling, and permit easy hand adjustment of the bolt.

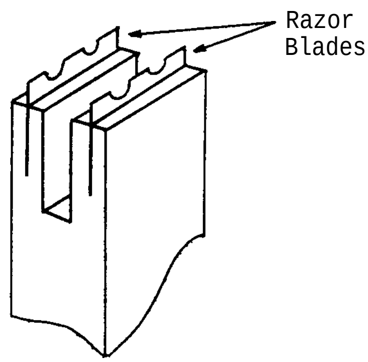
Bore an additional hole (approximately 0.2 cm diameter) at the center of the base to facilitate the attachment of the support.

(2) Support

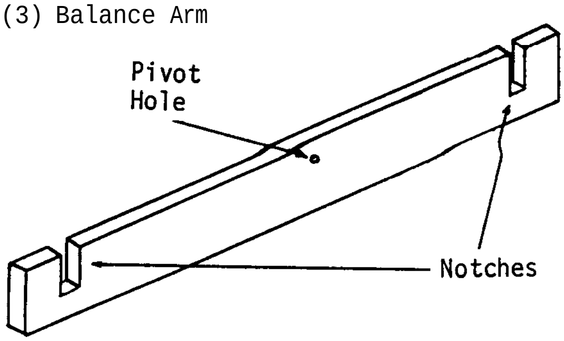
Cut the support to the shape shown from a piece of wood (E) and cut slots approximately 1 cm deep in the top surface with a saw. Attach the support to the base with the screw (D) inserted through the hole in the center of the base, making a strong junction with the help of wood cement. Then, cut the



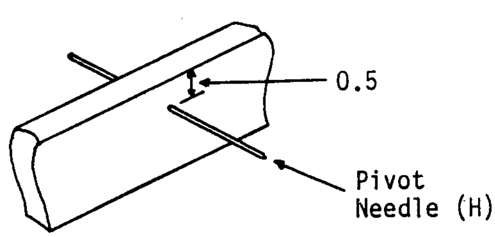
razor blade (F) in half, and, after smearing the cutting edges with epoxy resin, insert the cutting edges of the blades as deep as possible into the slits. The less the blades protrude above the wood the less the strain that is possible on the projecting blades.



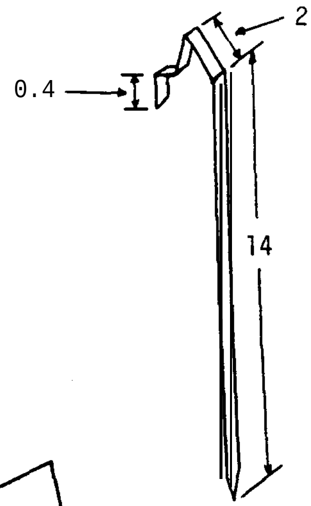
(3) Balance Arm



Make the balance arm out of softwood (G), cutting a notch (0.5 cm wide, 1.0 cm deep) at a distance of 1.5 cm from each end of the arm.

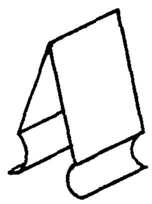


Drill a hole (0.1 cm diameter) horizontally through the middle of the arm at a distance of 0.5 cm from the top of the arm. Drive the steel needle (H) through the hole to serve as a pivot, and glue it permanently in position with epoxy resin.

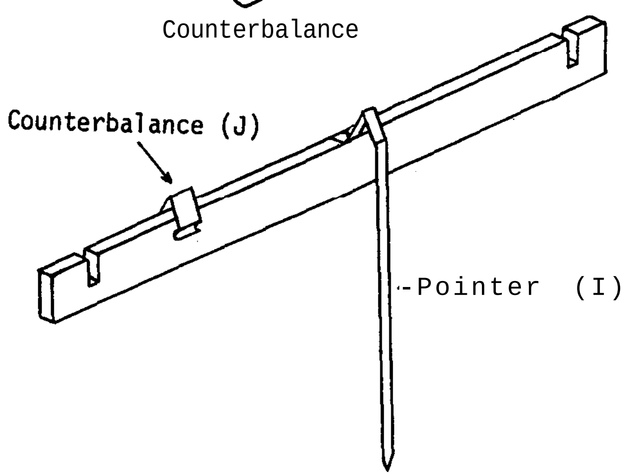


The needle must be sufficiently strong not to bend, even under heavy loads.

Take the sheet of aluminum (I) and bend it into the shape of a pointer as illustrated. Then attach the pointer to the middle of the balance arm.

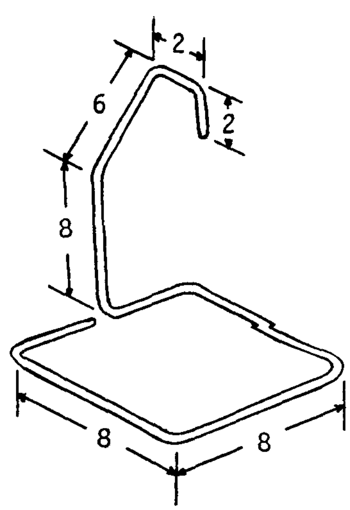


Counterbalance

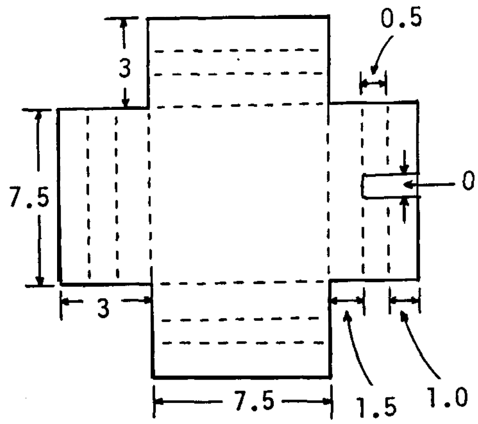


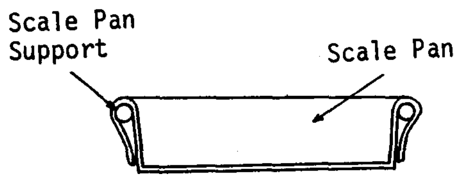
Complete the balance arm by making a small counterbalance from the sheet of aluminum (J), bending it to the shape indicated. Sit the counter-balance on the balance arm.

(4) Scale Pans



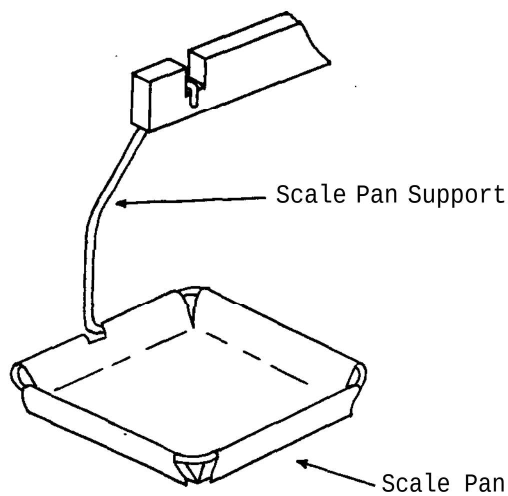
Take the length of aluminum or galvanized wire (K) and bend it into a support for the scale pan. Make an identical support in the same way, and suspend both supports from the notches in the balance arm,

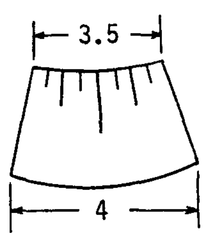




Cross Section

Make the scale pan from the sheet of aluminum (L). Cut squares (3 cm x 3 cm) from the sheet corners to make four projections on the sheet, and cut a slit in one of the projections as indicated. Fold the projections along the dotted lines converting the aluminum sheet into a scale pan with sides. Sit the scale pan on the framework of one of the support wires. Make a second scale pan in an identical manner.





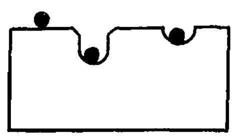
Make a small scale from a piece of white paper(M) by marking. regular divisions (0.3 cm apart approximately) on the paper. Glue the scale to the support just behind the pointer so that when the balance arm is perfectly horizontal the pointer will be at the middle of the scale.

c. hates

(i) The following table gives approximate values for the sensitivity of such a balance under varying loads. Sensitivity is measured as the number of milligrams required to cause the pointer to move one millimeter under the given load.

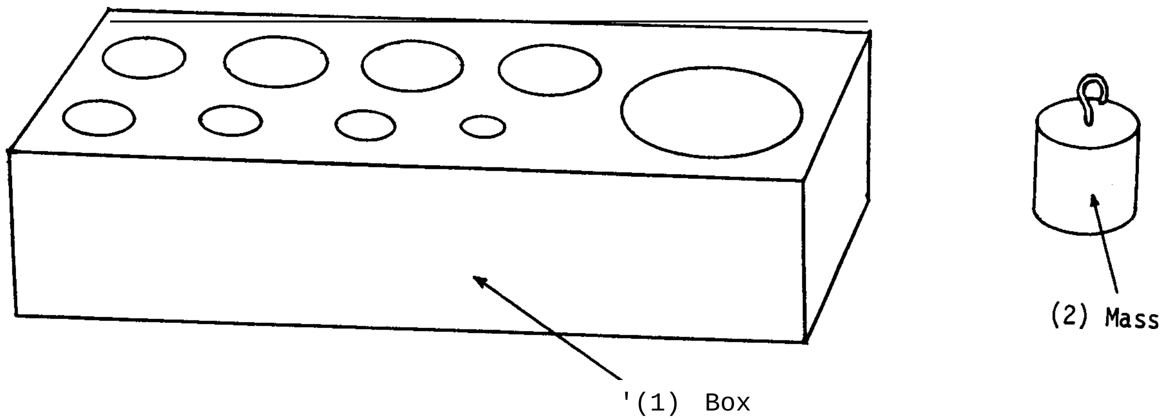
Load in Each Pan	Sensitivity
25 g	25 mg/mm
50 g	25 mg/mm
100 g	65 mg/mm
250 g	200 mg/mm
500 g	335 mg/mm

(ii) As seen in the illustration, the shape of the razor blade edge allows three different points to be used as fulcrums for the pivot needle. Sensitivity is found to be essentially the same at all three points for all weights.



(iii) The centering point of the pointer is very stable under varying weight loads. However, if the weights are shifted drastically in position in the pans (that is, off center) then shifts in the pointer position of up to 2 mm may be noted.

C2. Box of Masses©

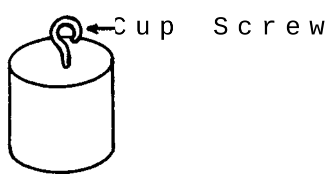


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Masses	1-3	Lead (A) (sheeting, etc.)	2 kg approximately
	9	Eye Screws (B)	--
(2) Box	1	Wood (C)	17 cm x 8 cm x 5 cm

b. Construction

(1) Masses



Take a box of wet sand, and use wooden dowels, or some such similar material, to make cylindrical molds in the sand according to the dimensions given below. Heat up some lead (A) in a can, and when it is molten pour it into the molds. Allow the lead to solidify and cool. Then screw into the top of each lead cylinder a cup screw (B) to serve as a handle.

The lead cylinders may then be filed down until each is the desired mass. The number of masses required, and the

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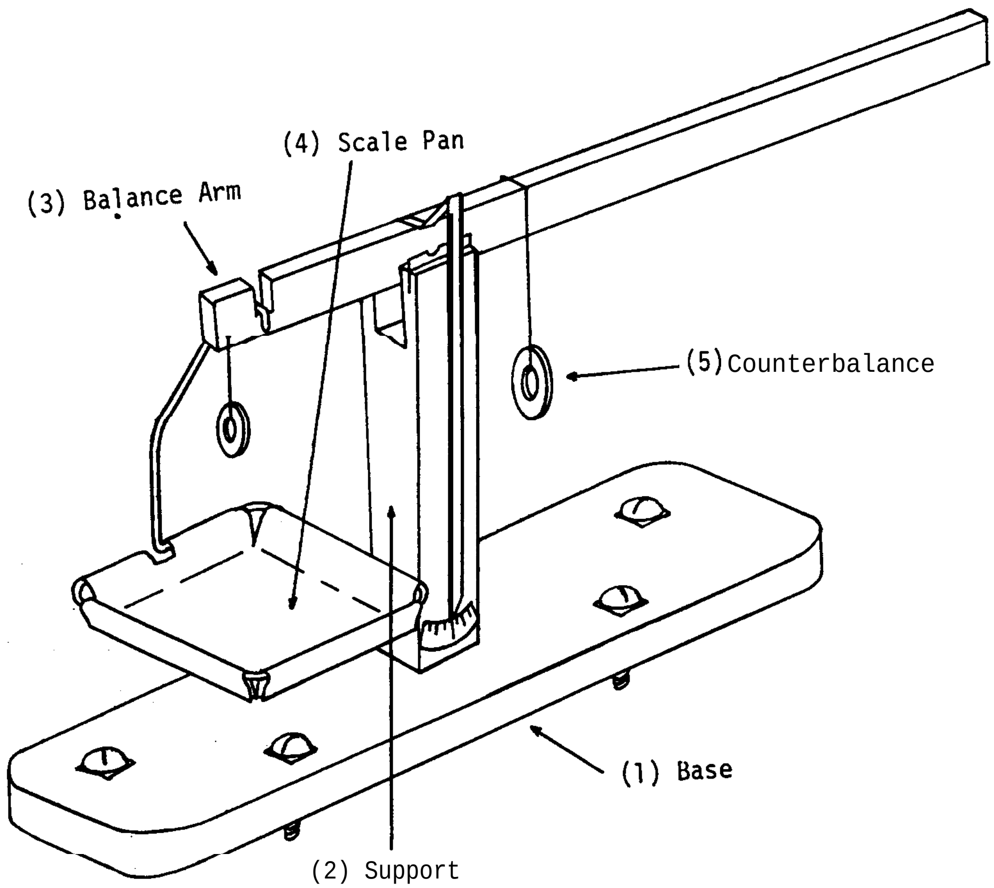
approximate size of each mold, is indicated below.

Qu	Weight	Diameter	Depth
1	500 g	3.8 cm	4.0 cm
3	200	2.4	4.0
1	100	2.4	2.0
1	50	2.4	1.0
2	20	1.2	2.0
1	10	1.2	1.0

(2) Box

Take the block of wood (C) and drill holes, the same size as the above molds, into the top surface. These will serve as suitable mass holders.

C3. Single Pan Balance



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Equal Arm Balance Base (A)	I/Cl Component (1)
(2) Support	1	Equal Arm Balance Support (B)	I/Cl Component (2)
(3) Balance Arm	1	Soft Wood (C)	42 cm x 2 cm x 0.5 cm
	1	Needle (D)	5 cm long
	1	Aluminum Sheet (E)	19 cm x 0.5 cm x 0.05 cm
(4) Scale Pan	1	Equal Arm Balance Scale Pan	I/Cl Component (4)
(5) Counterbalances	--	Washers (F)	Approximately 70 g total
	--	Washers (G)	Approximately 12 g total
	2	Paper Clips (H)	--

b. Construction

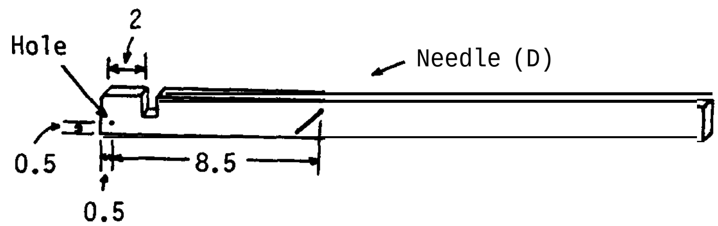
(1) Base

Make the base (Component 1) of the Equal Arm Balance (I/Cl) and use it as the base (A) of of this item.

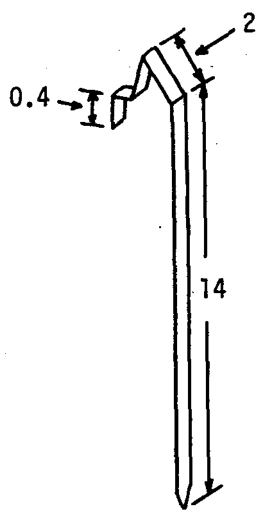
(2) Support

Make the support (Component 2) of the Equal Arm Balance (I/Cl) and use it as the support (B) of this item.

(3) Balance Arm



Make the balance arm from the soft wood (C). Drive the needle (D) horizontally through the arm 9 cm from one end and 0.5 cm from the top surface. Cut a notch (0.5 cm wide, 1.0 cm deep) in the top of the arm and drill a small hole (0.2 cm diameter) through the corner of the wood.



Take a sheet of aluminum (E) and bend it into the shape of a pointer as illustrated. Then attach the pointer to the arm just above the pivot.

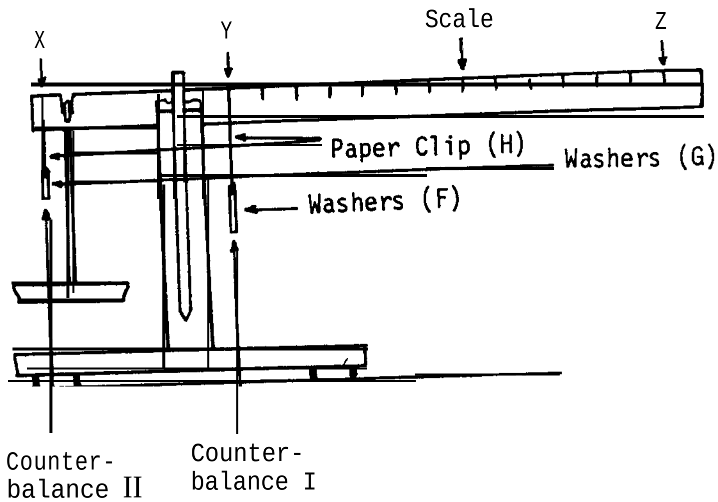
Sit the balance arm on top of the support so that the needle serves as a pivot.

(3) Scale Pan

Make the scale pan (Component 4) of the Equal Arm Balance (I/Cl), and suspend it from the notch in the balance arm.

(4) Counterbalance

If it is desired to use the balance to weigh the masses up to 300 g, a standard 300 g mass should be placed in the scale pan and washers (F) should be suspended from a paper clip (H) to make counterbalance (I).



Side View

The latter should be such that when it is suspended from the end of the balance arm (position Z) it will just balance the 300 g mass. (In this particular instance two washers weighing a total of 70 g were found to be ideal.)

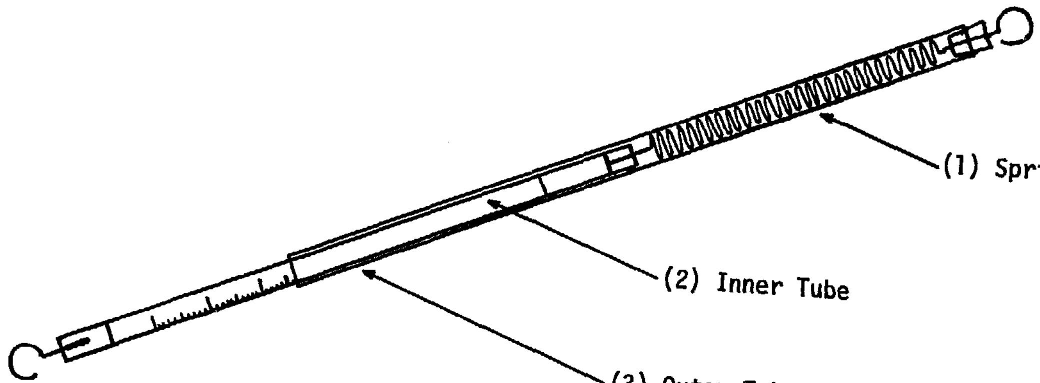
The counterbalance should then be moved to a suitable zero position (Y) on the arm. The balance arm will not remain horizontal. Therefore make a second counterbalance II from the small washers (G) such that when these are suspended from the end of the arm (position X) they will just balance the arm in a horizontal position with counterbalance I in the zero position (Y). (In this instance washers weighing a total of 12 g made a suitable counter-balance II).

You are now ready to calibrate the scale. Stick a piece of paper to the balance arm with adhesive tape to facilitate the marking of the scale. Then place standard masses (50, 100, 150, 200, 250, 300 g) in the scale pan, and in each instance determine the position of the counterbalance (I) which balances the arm. A uniform scale should be created, and this may be subdivided as desired.

c. **Notes**

(i) Alternative scales may be produced in an identical manner simply by altering the magnitude of counterbalance I (leaving the mass of counterbalance II the same as before). For example using only one washer (35 g) for counterbalance I a scale from 0 to 140 g was created on the same balance.

C4. Spring Balance ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Spring	1	Roll of Steel Wire (A)	#26 gauge (for 10 Newton Balance)
	1	Roll of Steel Wire (B)	#30 gauge (for 1 Newton Balance)
(2) Inner Tube	1	Hollow Aluminum Tube (C)	21 cm long, internal diameter 1 cm
	2	Wood Stoppers (D)	1 cm diameter, 2 cm long
	1	Cup Screw (E)	--
(3) Outer Tube	1	Hollow Aluminum Tube (F)	27 cm long, internal diameter 1.3 cm
	1	Wood Stopper (G)	1.3 cm diameter, 2 cm long
	2	Cup Screws (H)	--

b. Construction

(1) Spring

The most important factor in winding a spring is to keep the wire taut at all times, and for this the help of a

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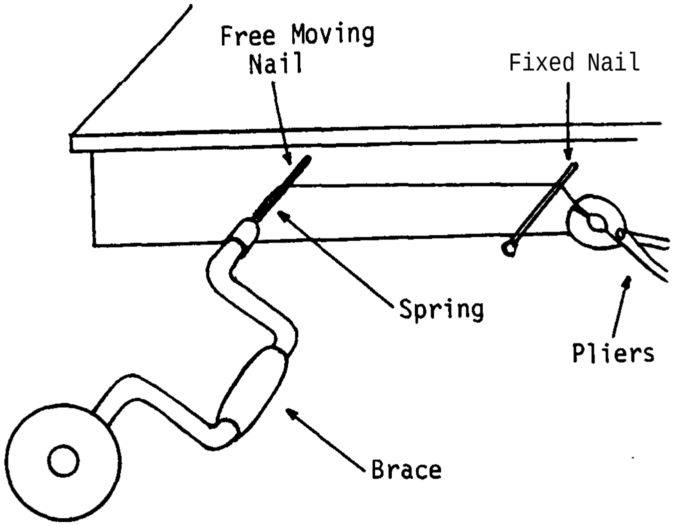
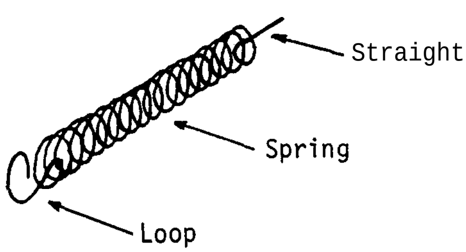


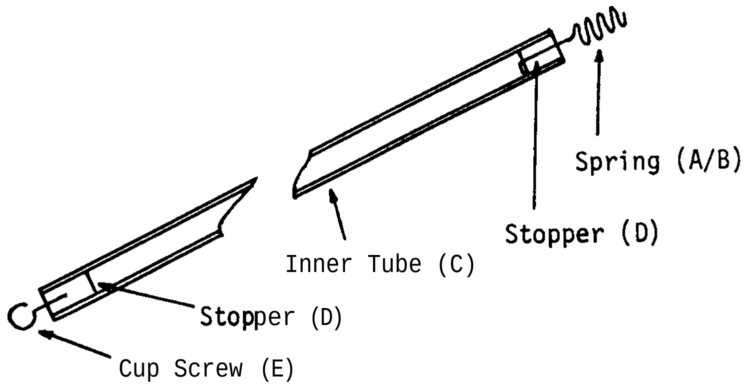
brace and two nails (10 cm long, 0.7 cm diameter) is invaluable. Drill a horizontal hole about 3 cm deep in the bench for the free moving nail, and about 20 cm to the right of this drive in a second (fixed) nail. Clamp one end of the wire (A/B) along with the head of the free nail in the jaws of the brace, and get your partner to hold the other end of the wire in the jaws of a pair of pliers, keeping the wire taut with the assistance of the fixed nail. Turn the brace, winding the wire firmly around the free nail, The spring may be close wound (each turn touching the next) or open wound (each turn separated from the next by a fixed distance). Although the wire is wound on a nail of diameter 0.7 cm, on release from tension it will tend to expand to about 1 cm diameter.

If a Newton balance is to be made take the #26 gauge steel wire (A) (diameter 0.07 cm) and open wind it (0.1 cm between each turn) into a spring approximately 8 cm long and 0.9 cm in diameter.



Make a loop on one end of the spring (using dog nosed pliers) and a straight piece on the other end.

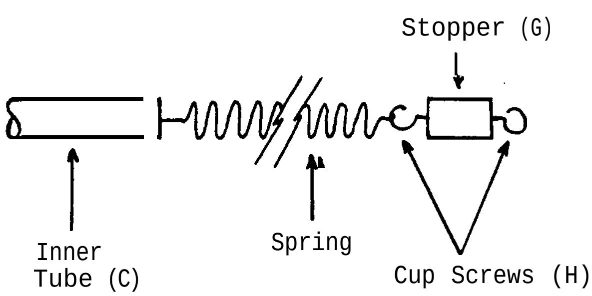
(2) Inner Tube



Cross Section View

Make two stoppers out of the wood (D). Fix a cup screw (E) into one of the stoppers and glue it permanently into one end of the aluminum tube (C). Drill a small central hole through the other stopper (D) and insert the straight end of the spring, bending the end over to hold it in position. Glue the stopper into the other end of the tube.

(3) Outer Tube



Detail

Make a wooden stopper (G) to fit one end of the hollow aluminum tube (F). Fix cup screws (H) in either end of the stopper, and attach the top of the spring to one of the cup screws,

Now take the combination of stopper, spring and inner tube, and lower it into the outer tube (F) until the stopper lodges in the top of the tube. Glue the stopper firmly into the tube.

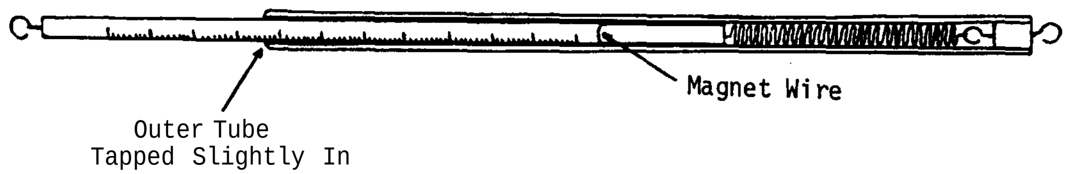
C. Notes

(i) To calibrate the 10 Newton spring, hold the balance vertically, and mark the inner tube opposite the lower end of the external tube (10 Newtons). Suspend 1,020 g from the spring and once again mark the inner tube opposite the lower end of the external tube. Then subdivide the distance between the two marks into 100 equal divisions, thus permitting the balance to read from 0.0 to 10.0 Newtons with an accuracy of 0.1 Newtons.

(ii) To calibrate the 1 Newton spring simply suspend a mass of 102 g from the balance and repeat the above process, calibrating the inner tube from 0.00 to 1.00 Newtons with an accuracy of 0.01 Newtons.

(iii) Spring balances are very easily damaged by over extension of the spring. It is therefore useful to make some simple device to prevent over stressing the spring.

One such method is to tie a piece of magnet wire (diameter 0.05 cm) around the inner cylinder, just above the final marking on the scale, If the lower perimeter of the outer tube is then tapped gently all around it, the magnet wire will be unable to move beyond this point, thus preventing over extension of the spring.



Cross Section

II. TIMING DEVICES

Timing devices have been divided into three groups according to the length of time intervals they would most conveniently measure. This categorization is somewhat arbitrary, and it follows that some devices could, under certain circumstances, exist in more than one category. The categories are defined as follows:

A. LONG INTERVAL TIMERS

The intervals to be measured may range from a day (month, year) down to an hour or minute.

B. MEDIUM INTERVAL TIMERS

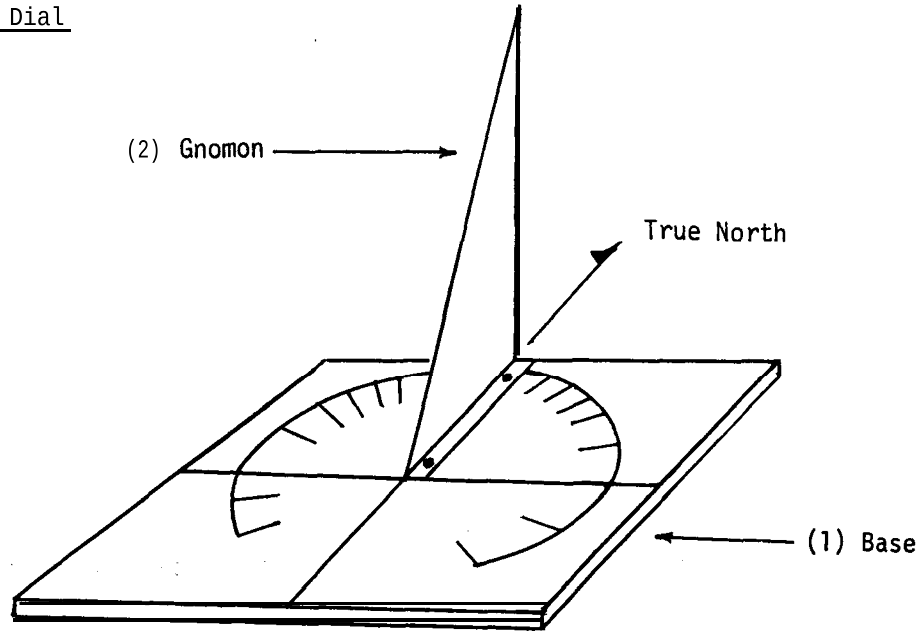
The intervals to be measured would range from minutes to seconds.

C. SHORT INTERVAL TIMERS

The intervals to be measured are subdivisions of a second.

A. LONG INTERVAL TIMERS

Al. Sun Dial

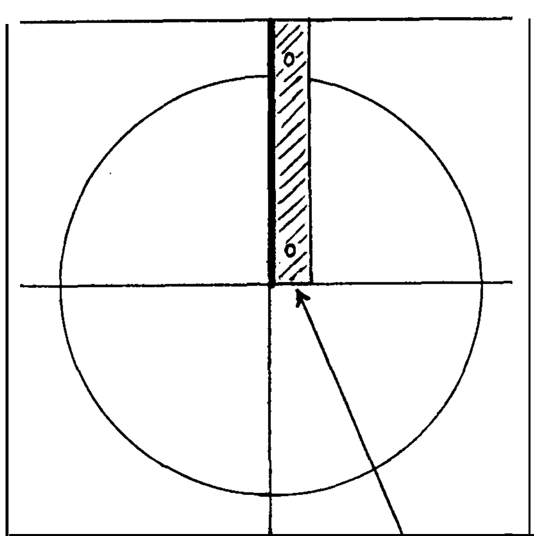


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	16 cm x 16 cm x 2 cm
(2) Gnomon	1	Metal Sheet (B)	10 cm x 8 cm x 0.1 cm

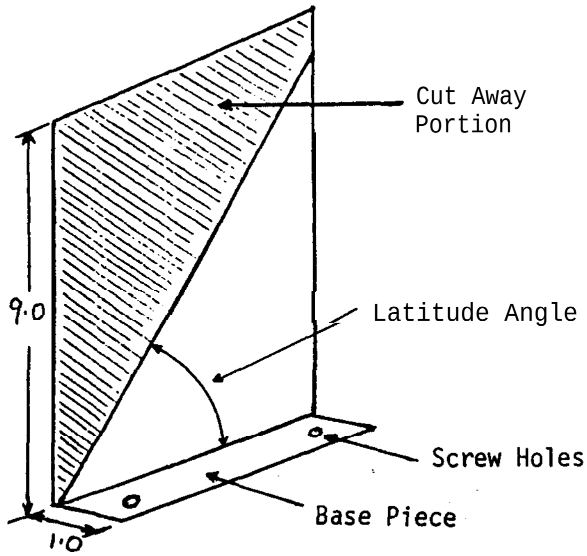
b. Construction

(1) Base



Cut the base from the wood (A). Use a felt pen to mark off the surface of the base into four equal portions. Draw a circle (diameter 7 cm) on the base with its center at the middle of the base.

(2) Gnomon



Make the gnomon from the metal sheet (B). Bend the end of the sheet at right angles to the sheet so as to form a base piece 1 cm wide. Drill two screw holes in the base piece. Note the latitude of your locality (e.g., 39° in Washington, D.C.) and mark out a right-angled triangle on the vertical portion of the metal sheet such that the sloping side of the triangle is inclined to its base at an angle equal to the latitude angle. Cut off the sheet above the sloping side. You now have a metal gnomon. Attach the gnomon to the base with screws.

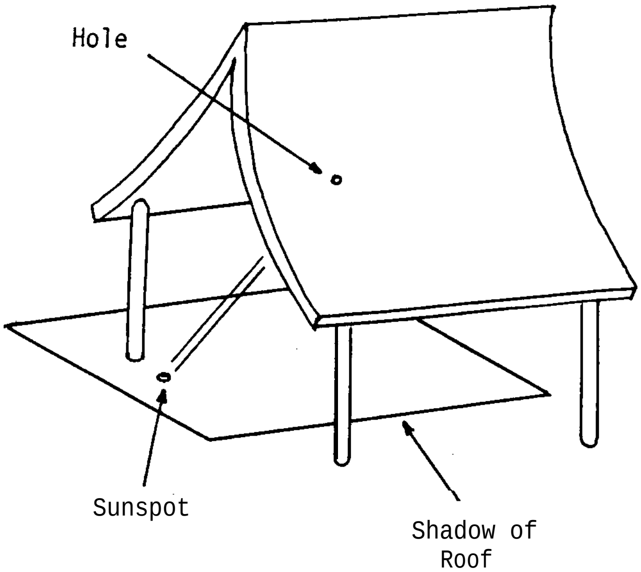
C. Notes

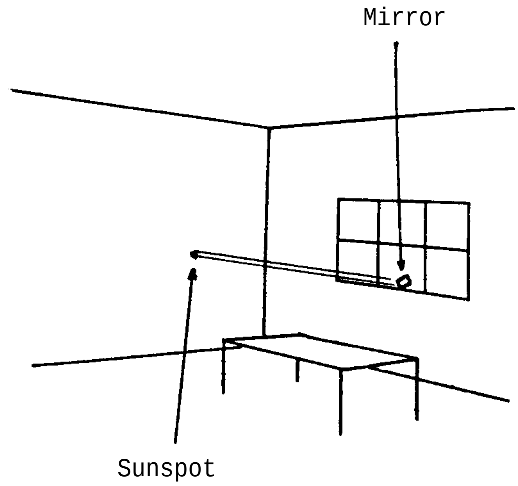
(i) The base of the apparatus should be placed on a horizontal surface with the plane of the gnomon in a true North-South plane, thus making the sloping side of the gnomon parallel to the Earth's axis. Calibrate the sun dial against a clock, marking in the positions of the shadow with a felt pen or paint.

(ii) At the North and South Poles the shadow will move through 15° every hour. Elsewhere the angle rotated per hour will be greater than 15° in the early morning and late evening, and less than 15° towards midday.

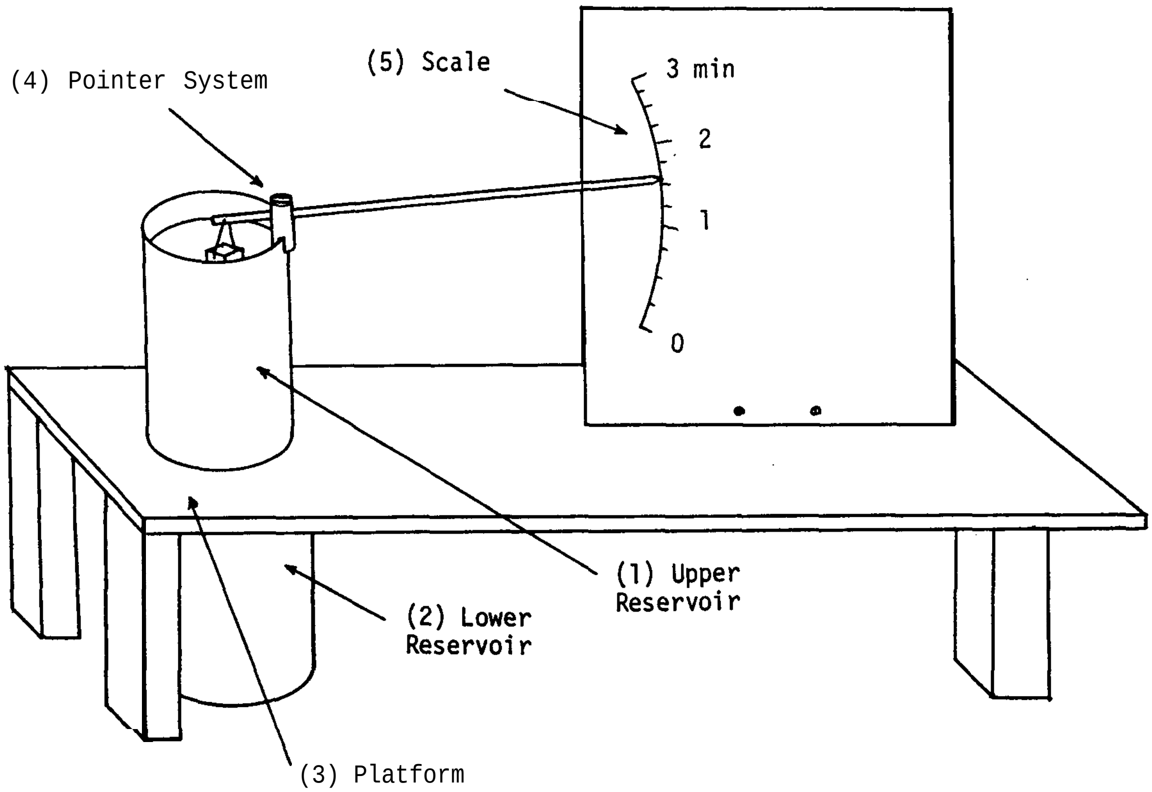
(iii) Since the rotation of the Earth is not exactly 24 hours, the sun will not appear to be due North (or South, as the case may be) at noon, Greenwich Mean Time. Each month it will therefore be noted that the sun dial deviates further and further from the conventional time. From 5 to 30 minutes deviation will be noted over a period of one month, depending on the season.

(iv) The apparent motion of the sun may be used in even simpler (but cruder) ways to record the passage of time. It is thus possible to note the motion of a spot of sunlight due to a ray of light passing through a hole in a roof, or due to a ray of light reflected from a mirror placed by a window. The distance moved by the sunspot in successive intervals of time on the same day will be noted to be surprisingly regular. (See sketches on next page.)


Hole
Sunspot
Shadow of
Roof


Mirror
Sunspot

A2. Water Clock



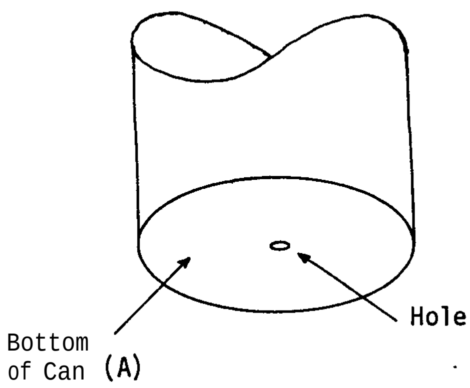
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Upper Reservoir	1	Can (A)	1 liter capacity
(2) Lower Reservoir	1	Can (B)	1 liter capacity
(3) Platform	1	Plywood (C)	50 cm x 15 cm x 1.0 cm
	3	Wood (D)	20 cm x 3 cm x 3 cm
(4) Pointer System	1	Wooden Dowel (E)	B cm long, 2.5 cm diameter
	1	Wood Strip (F)	35 cm x 0.6 cm x 0.4 cm
	1	Nail (G)	0.2 cm diameter, 4 cm long
	4	Washers (H)	--
	1	Wood (I)	4 cm x 4 cm x 1 cm
	1	String (J)	--
	1	Eye Screw (K)	--

(5) Scale	1	Plywood (L)	40 cm x 30 cm x 0.5 cm
	1	Wood (M)	30 cm x 3 cm x 3 cm
	1	White Paper (N)	30 cm x 40 cm

b. Construction

(1) Upper Reservoir



Take the tin can (A) and drill a small hole (0.1 cm diameter for example) in the middle of the base.

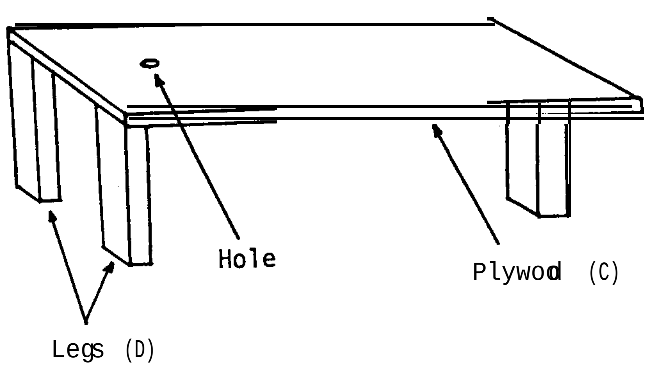
The bigger the can, and the smaller the hole, the greater will be the period of time for which the clock will run. This may be checked now by filling the can with water, and noting the time for it to drain.

If you wish to measure small intervals of time, you may increase the number of holes in the base of the can.

(2) Lower Reservoir

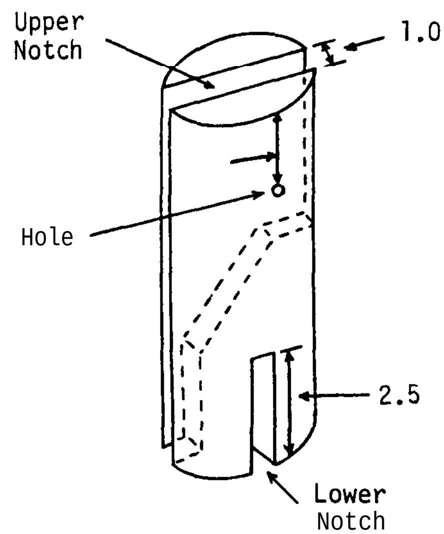
Use can (B) which should be of the same size as, or larger than, the can used for the upper reservoir.

(3) Platform

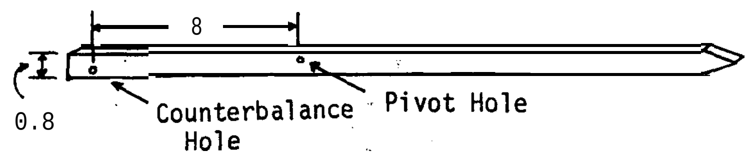


Take plywood (C) to make the platform, balancing this on the three legs (D) which should be sufficiently long to permit the lower reservoir to be moved under the platform without difficulty. Drill a hole (1 cm diameter) in one end of the platform. Place the upper reservoir over the hole in the platform and the lower reservoir underneath it so that water can run from the upper to lower reservoir.

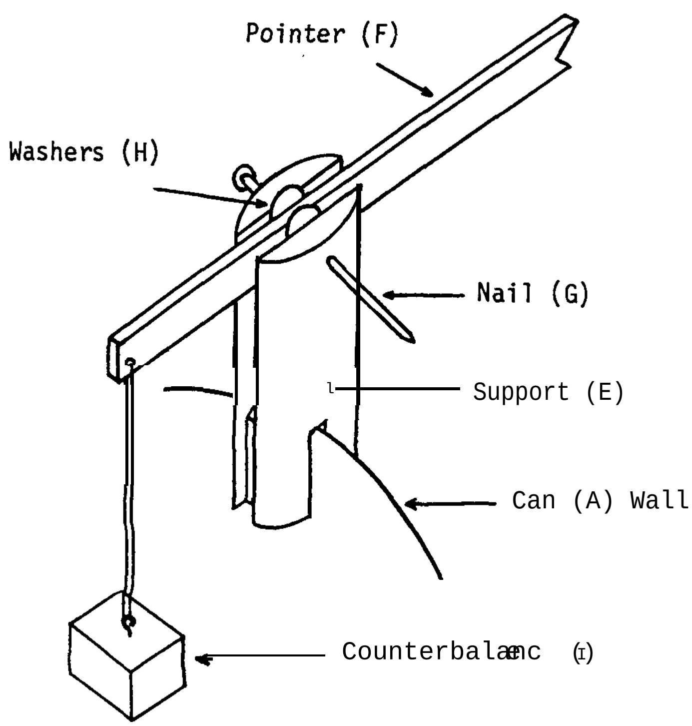
(4) Pointer System



Make a support from a wooden dowel (E) as indicated. Cut a lower notch in the support to enable it to sit on the side of the upper reservoir (A). Make an upper notch to permit the full movement of the pointer (E) to be attached. Drill a hole (0.2 cm diameter) horizontally through the upper part of the support to permit passage of the nail (G) to serve as the pivot for the lever.



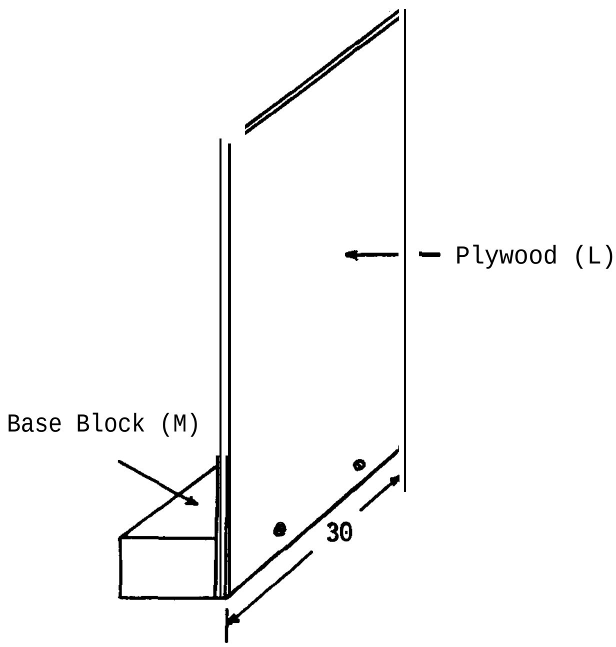
Make the pointer from a strip of wood,(F). Drill a small hole (0.3 cm diameter) at one end of the pointer to take the string (J) from the counter-balance, and 8 cm away from this hole drill a second hole (0.3 cm diameter), close to the top surface of the pointer, through which the nail (G) is to be put as a pivot.



Balance the pointer on the newly made support by inserting the nail (G) through the appropriate holes in the support and pointer. Washers (H) should be placed either side of the pointer to serve as spacers. These prevent unwanted motion of the pointer on the pivot. The pivot may be fixed permanently in position in the support with the help of epoxy resin, since the pointer can move about the fixed axle on its own pivot hole.

Take the small block of wood (I), and attach it to the pointer by means of the string (J) and a screw (K) attached to the top of the block.

(5) Scale



Attach a sheet of plywood (L) to the block of wood (M) intended to hold the plywood in a vertical position. Sit the newly made scale on the platform just behind the end of the pointer, sufficiently close to avoid parallax problems in recording the movement of the pointer. Screw the base block (M) of the scale onto the platform. Use a white sheet of paper (N) attached to the surface of the plywood with thumbtacks to actually record a time scale.

Adjust the length of string (J) on the counterbalance so that when the upper reservoir is full of water the pointer will be set towards the bottom edge of the scale.

C. Notes

(i) The counterbalance should be wet all over prior to use so that it does not tend to sink deeper into the water as it is used.

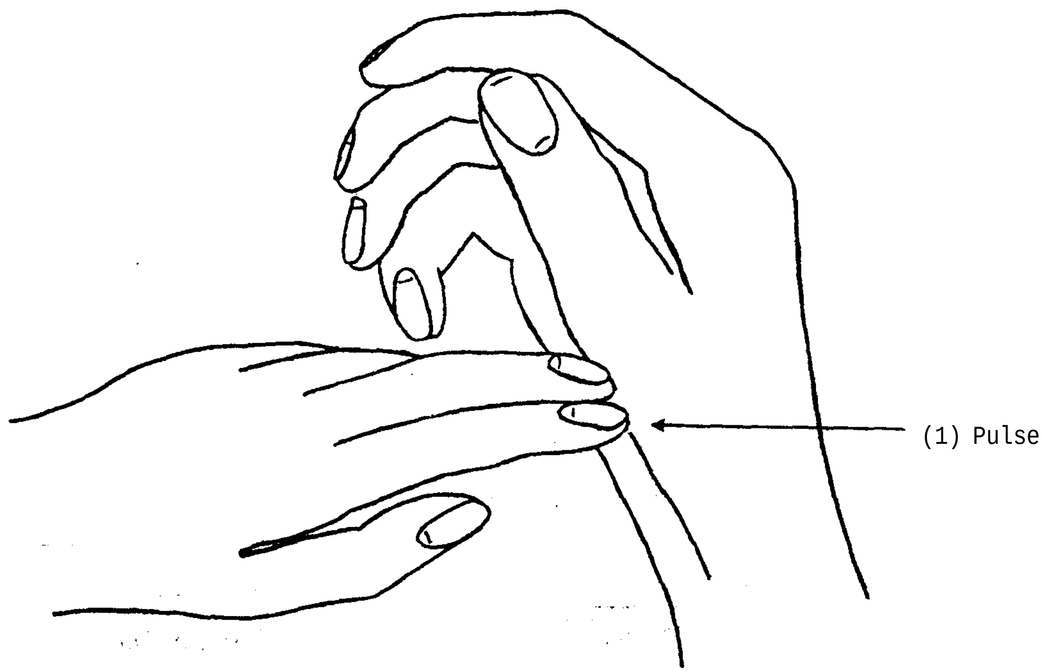
(ii) The water clock may be calibrated against a watch. The scale produced will not be linear since the water pressure over the hole in the base of the upper reservoir decreases as the water level drops. The initial rate of fall of water level is therefore greater than the final rate.

(iii) The clock will be found to be surprisingly reliable, observations being quite repeatable.

(iv) Using an upper reservoir of 1.3 liters, a depth of 19 cm and a base hole 0.15 cm diameter, a five-minute scale was very conveniently created. When the number of holes in the base was doubled the pointer traversed the scale in half the time (2 min 30 sec), and when the number of holes was increased to three the pointer traversed the scale in one third of the original time (i.e., in 1 min 40 sec).

B. MEDIUM INTERVAL TIMERS

Bl. Pulse



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Pulses	--	--	--

b. Construction

(1) Pulse

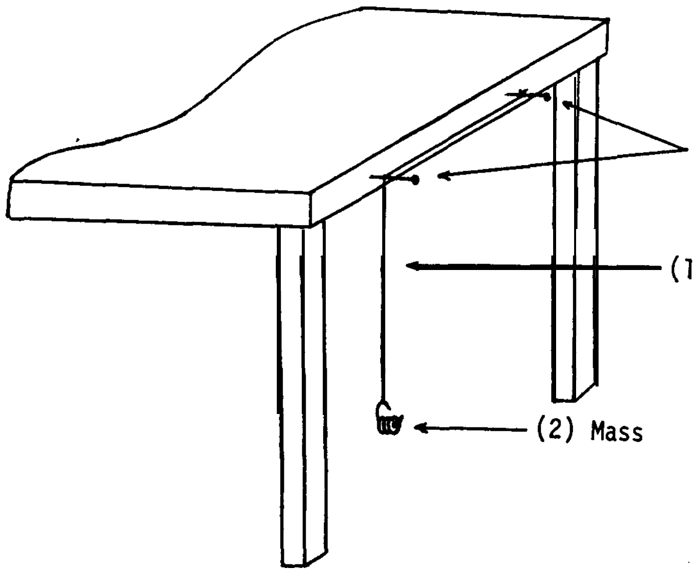
Place two fingers from the left hand over the pulse on the right wrist. The pulse beat can easily be detected.

c. Notes

(i) The pulse beat may be calibrated against that of other individuals and against other timing devices. Under normal conditions it remains surprisingly constant, but its rate varies according to the degree of exertion to which the individual is currently subjected.

(ii) It is useful to note that if the pulse in the neck, just below the angle of the jaw, is monitored with one hand, the other hand is left free for other functions.

B2. Simple Pendulum



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) String	1	String (A)	1 meter long
	1	Paper Clip (B)	--
(2) Mass	10	Washers (C)	--
(3) Support	2	Nails (D)	3 cm long

b. Construction

(1) String

Take the length of string (A), and attach a hook [made from the paper clip (B)] to one end.

(2) Mass

Suspend washers (C) from the hook to serve as a variable mass.

(3) Support

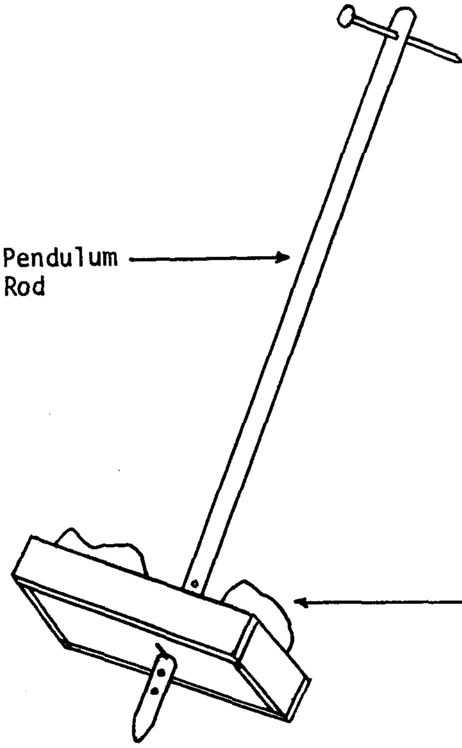
Drive two nails (D) into the side of a table, or into a wall, so that the nails are at the same height above the ground. Wrap the desired length of string two or three times around one nail, and fasten the spare length of string to the other nail. This should insure that

the string is pivoted rigidly
at the first nail.

C. Notes

(i) If the length of the pendulum, from the support to the center of gravity of of the mass, is adjusted t 25 cm (or more accurately to 24.8 cm) the pendulum will oscillate with a period of one second.

B3. Classroom Clock*



a. Materials Required

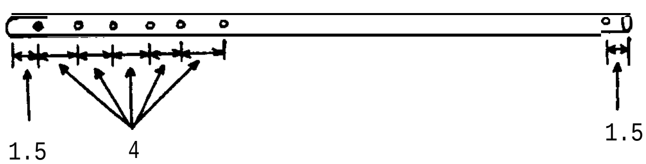
Components	Qu	Items Required	Dimensions
(1) Pendulum Rod	1	Broom Handle (A)	120 cm long, 2.5 cm diameter
	1	Metal Tube (B)	2.5 cm long, 1 cm external diameter; approximately 0.7 cm internal diameter
	1	Nail (C)	15 cm long, 0.5 cm diameter
(2) Mass	2	Wood (D)	22 cm x 6 cm x 0.5 cm
	2	Wood (E)	30 cm x 6 cm x 0.5 cm
	1	Wood (F)	31 cm x 22 cm x 0.5 cm
	1	Nail (G)	10 cm long, 0.5 cm diameter
	--	Bricks, Rocks, etc. (H)	--

*Adapted from Nuffield Foundation, Guide to Experiments I, Physics, (London: Longmans/Penguin, 1967), pp 79431.

(3) Support	2	Tables (I)	--
	2	Stools (J)	--

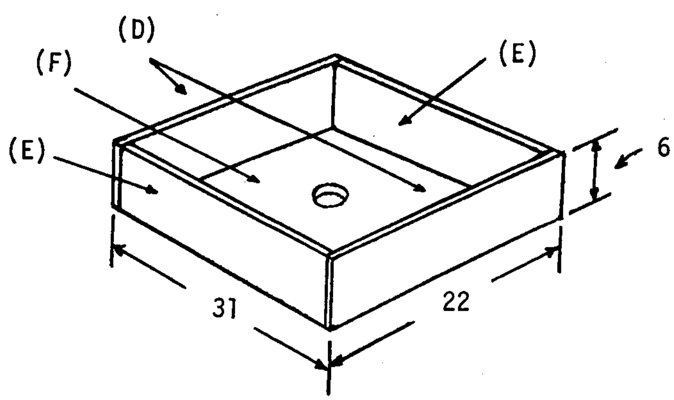
b. Construction

(1) Pendulum Rod



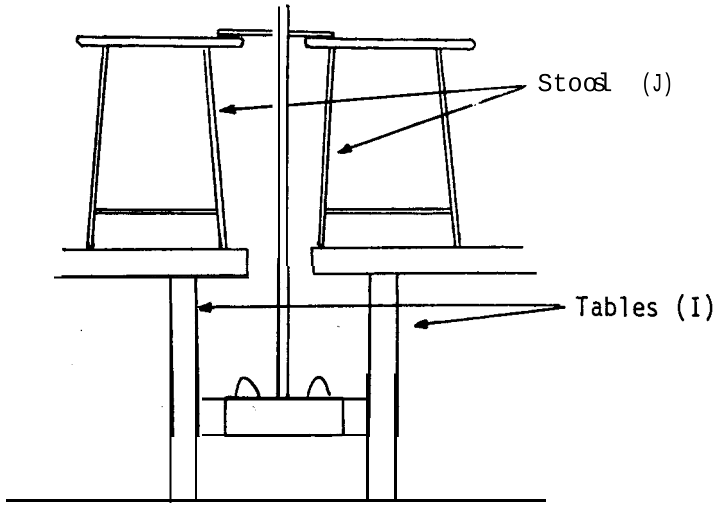
Make the pendulum rod out of the broom handle (A). Drill six holes (0.6 cm diameter) in one end of the rod at 4 cm intervals. Drill another hole (1 cm diameter) 1.5 cm from the other end of the rod. Line this with a short length of metal tubing (B) to reduce friction at the pivot, and insert a long nail (C) through the tube.

(2) Mass



Construct a wooden tray to hold the masses. Use one piece (F) for the base. Nail the four other pieces (D,E) to the base as shown. Drill a hole (2.7 cm diameter) in the middle of the tray base (F), and slide the tray onto the pendulum rod by way of this hole. Insert the strong nail (G) through one of the six holes in the end of the rod to hold the tray in position. The bricks or rocks (H) may be placed in the tray t0 serve as appropriate masses.

(3) Support



Place two tables (I) fairly close together, and sit the stools (J) on top of both tables, sufficiently close to one another so that the pendulum may be supported by means of its pivot nail resting between the tops of the stools. The nail (G) must be held firmly in position on top of the stools hand, clamps, or any device which will hold it firmly.

C. Notes

(i) With the length (L) of the pendulum from pivot to tray bottom fixed at 103.5 cm the period (T) of the pendulum was noted to be two seconds.

Mass = 7,000 g

L (cm)	T (sec)
97.0	1.94
101.0	I.98
105.0	2.02
109.0	2.05
113.0	2.09
117.0	2.12

(ii) The initial displacement of the pendulum mass has negligible effect on the period. Keeping the length of the pendulum fixed at 105 cm and the mass constant at 7,000 g the following correlation of period (T) and initial displacement (D) was recorded.

D (cm)	T (sec)
5	1.99
10	2.01
15	2.00
20	2.00

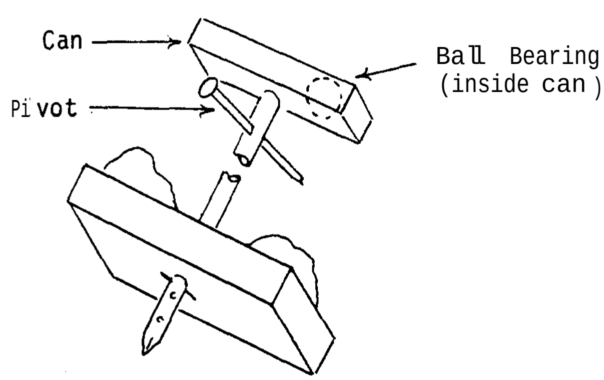
(iii) The period of the swing is virtually unaffected by variation of the mass. Hence, keeping the pendulum length constant at 105 cm, the mass (M) in the pendulum tray was varied by increasing the number of bricks. The following observations of the period (T) were recorded.

M (g)	T (sec)
1500	2.00
3250	2.00
5000	2.00
7000	2.01

(iv) The major effect of increasing the mass (M) of the bricks carried by the pendulum is to reduce the damping effect on the oscillations. With the length of the pendulum fixed at 105 cm, the pendulum mass was displaced a fixed distance (10 cm) and the number of oscillations (N) recorded as the displacement fell from 10 to 5 cm. The following results were obtained.

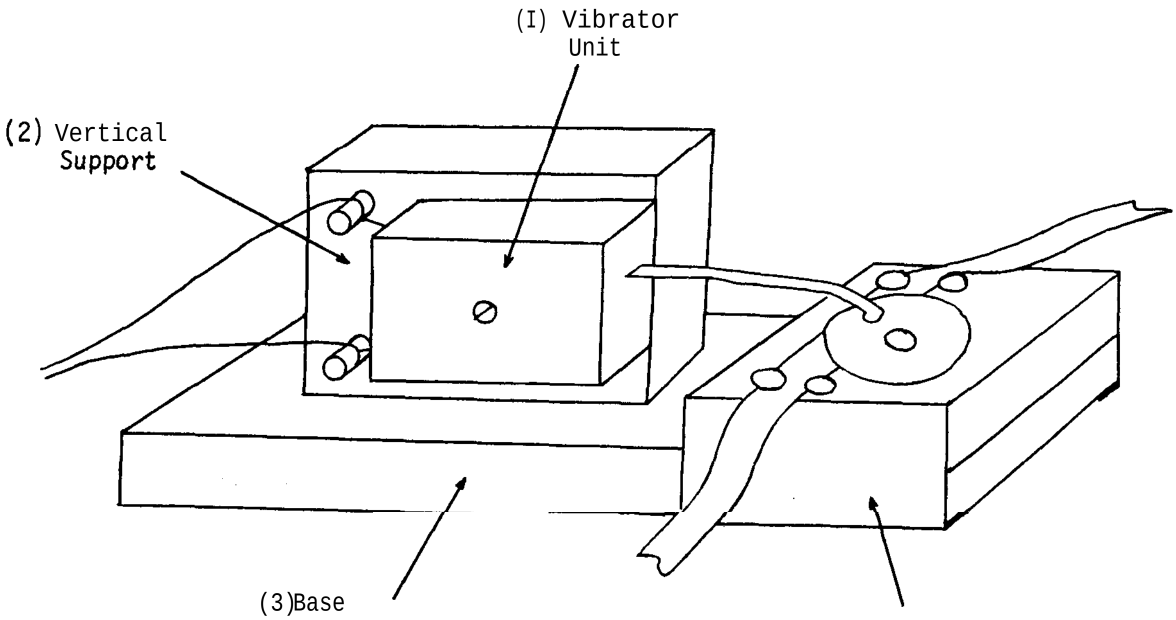
M (g)	N	Damping Effect
0	51.0	High
1500	95.5	Moderate
3250	97.8	Moderate
5000	98.2	Moderate
7000	131.6	Low

(v)fI this timing device is to be used by a large class, it might be useful to modify it slightly to make the counting of oscillations possible without continuous visual observation. It is suggested that a metal container might be attached to the top of the pendulum rod, and a 2.5 cm ball bearing allowed to roll freely in the container, so that a click will occur twice per oscillation as the ball bearing hits the ends of the can.



C. SHORT INTERVAL TIMERS

C1. Ticker Tape Timer ©



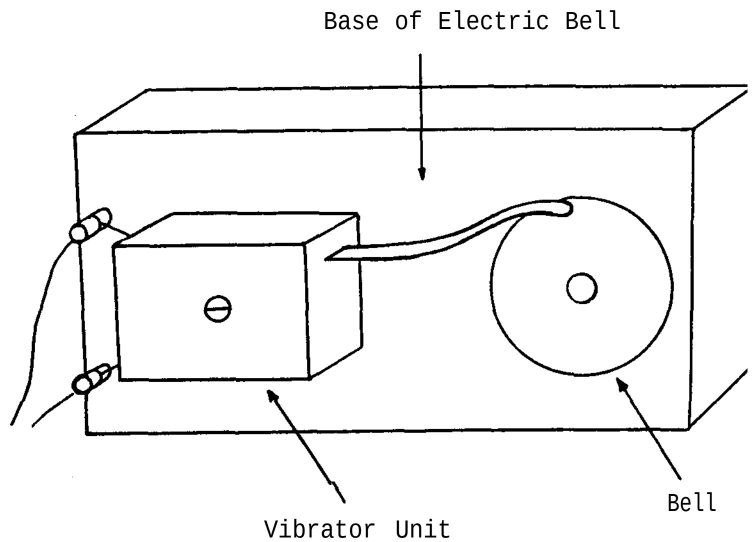
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Vibrator Unit	1	Household Electric Bell (A)	--
(2) Vertical Support	1	Wood (B)	7 cm x 5 cm x 2 cm
(3) Base	1	Wood (C)	16 cm x 6 cm x 2 cm
	2	Screws (D)	3 cm long
(4) Platform	1	Wood (E)	6 cm x 5 cm x 2 cm
	2	Aluminum Sheet (F)	6 cm x 5 cm x 0.05 cm
	1	Carbon Paper (G)	4 cm x 4 cm
	5	Thumbtacks (H)	--

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, London: Center for Educational Development Overseas 1972), pp 12-14.

b. Construction

(1) Vibrator Unit

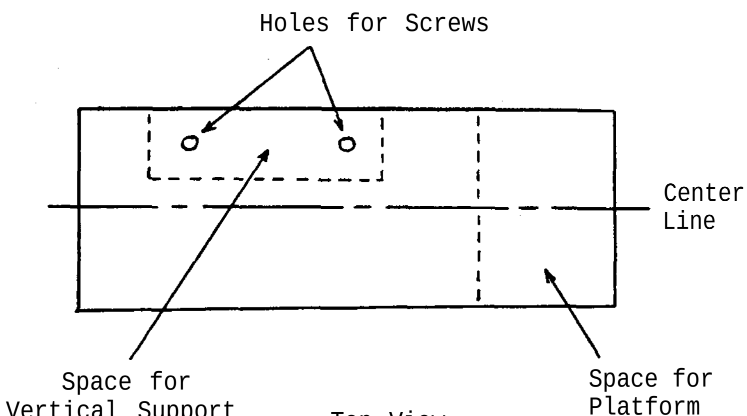


Take the household electric bell (A), and remove the vibrator unit. (The bell utilized in this instance was designed to operate normally at 10 volts.)

(2) Vertical Support

Use the piece of wood (B) to serve as the vertical support, and attach the vibrator unit to it with screws.

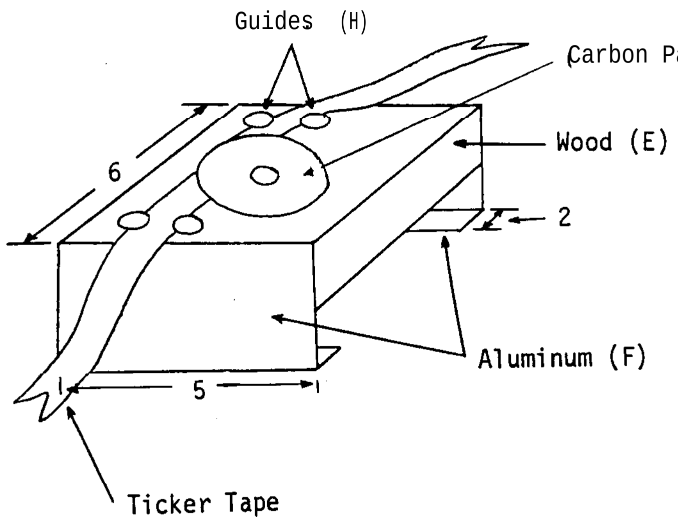
(3) Base



Top View of Base (C)

Use the wood piec (C) as the base. Place the vertical support on the base in such a position that the vibrator arm will be parallel to, and directly above, the line bisecting the length of the base. Mark in the position of the support, and then drill two appropriate holes in the base so as to facilitate the attachment of the support with the screws (D).

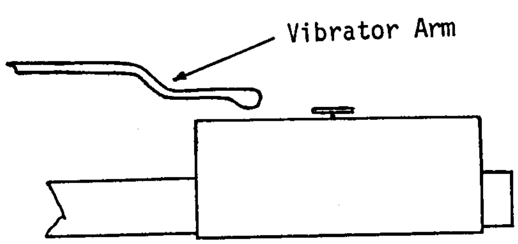
(4) Platform



Attach the aluminum sidepieces (F) to wood (E) with nails to make a platform. Then with the platform in position on the base, bend the sidepieces at the bottom to hold the platform firmly in contact with the base. (A loosely fitting platform will result in a poor track being recorded on the ticker tape.)

Cut a circular disc out of the carbon paper (G) and pierce the center so that it may pivot freely about a thumbtack (H) in the center of the platform.

Pin four more thumbtacks (H) in the platform to serve as guides for the ticker tape, which must pass under the carbon disc. There must be negligible friction between the guides and ticker tape.



Side View

Bend the vibrator arm downwards so that the endpiece is within 0.3 or 0.4 cm of the platform surface.

C. Notes

(i) Two dry cells in series will generally operate the timer, even though the bell is designed for operation on a 10 volt supply.

(ii) If ticker tape is difficult to obtain, cashiers' paper rolls (for cash registers) are generally available, and may be cut into strips of suitable width, so long as care is taken to obtain smooth straight edges.

(ii) If the ticker tape from the vibrating timer is attached to a moving object, the motion of the object will be recorded on the ticker tape. It is thus possible to determine the distance moved by the object during specific time intervals. This is the basis of a wide range of experiments to determine the relationship between force and motion.

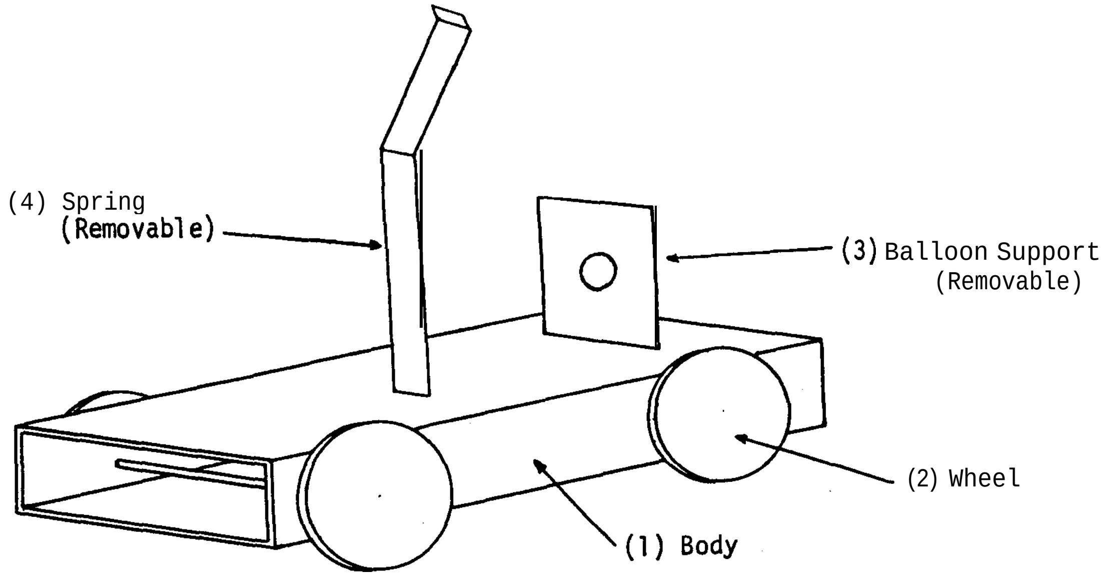
III. CARTS

A. FORCE AND MOTION CARTS

The carts described in this section are presented in increasing order of sophistication, ranging from the simplest cart which can only be used for qualitative observation to the more sophisticated carts which can be used for quantitative experimentation of the relationship between force, mass and acceleration.

A. FORCE AND MOTION CARTS

Al. Elementary Cart *



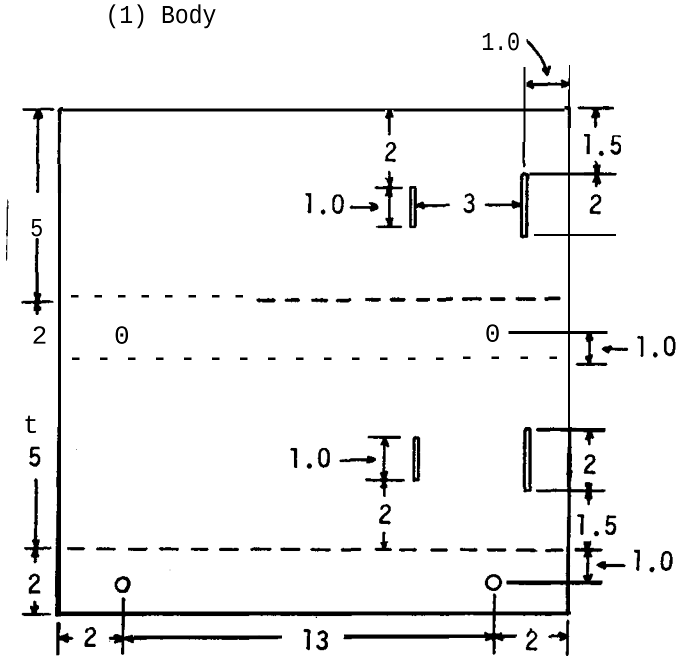
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	1	Cardboard Sheet (A)	15 cm x 14 cm
(2) Wheels	2	Wooden Spools (B)	Diameter of spool ends approximately 4 cm
	2	Coat Hanger Wire (C)	8 cm long, 0.2 cm diameter
	1	Drinking Straw (D)	--
(3) Balloon Support	1	Cardboard Sheet (E)	4 cm x 7 cm
	1	Balloon (F)	--
(4) Spring	1	Packing Case Band (G)	11 cm long, approximately 1.2 cm wide
	1	Washer (H)	Approximately 17 g

*Adapted from Nick Oddo and Edward Carini, Exploring Motion, An Exploring Science Book, (USA: Holt, Rinehart and Winston Inc., 1964), pp 24-27.

b. Construction

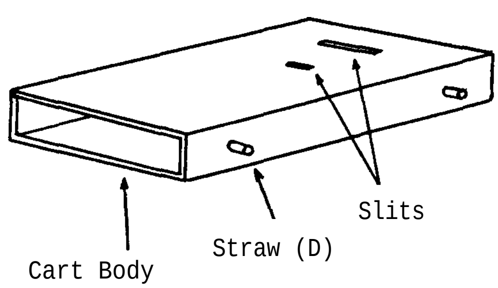
(1) Body



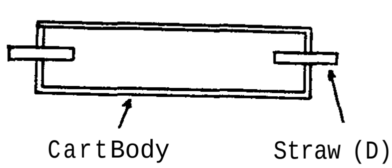
Cardboard (A)

Draw dotted lines on the piece of sturdy cardboard (A) and make four slits and four axle holes as illustrated in the diagram. Fold the cardboard along the dotted lines to make a box, fastening the free sides together with the help of adhesive tape.

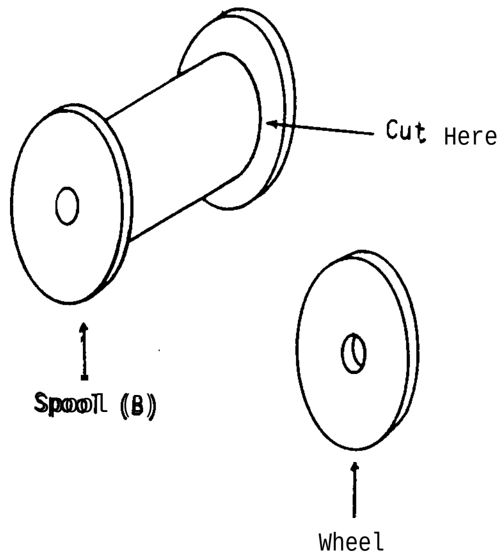
(2) Wheels



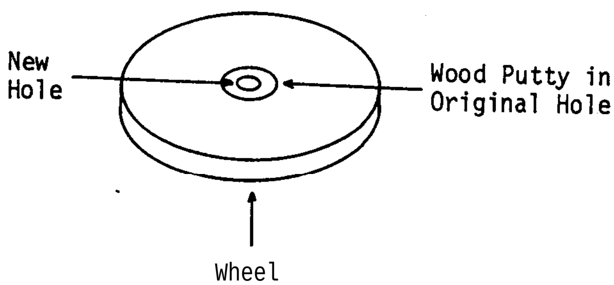
Cut four equal sections (each 1 cm long) from a standard drinking straw (D). Place each section into an axle hole in the body of the cart, and glue firmly in position. The straw sections act as bearings for the axles as well as spacers between the wheels and the body of the cart.



Cross Section



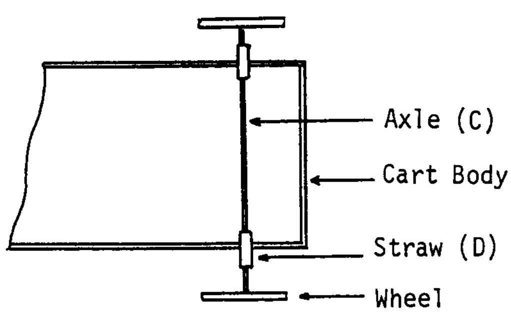
Cut the four wheels from the ends of the two wooden spools (B). Fill the spool holes (0.5 cm diameter) with wood putty and allow the putty to dry hard.



Cut two lengths of wire (C) from wire coat hangers to serve as axles for the cart.

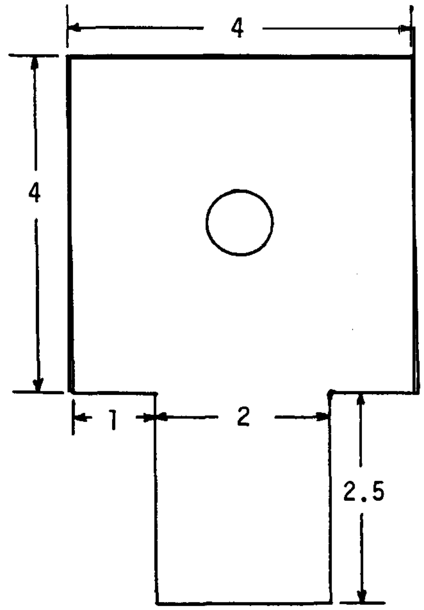
Drill holes, slightly less than 0.2 cm in diameter, through the exact center of each wheel, and put a little epoxy resin in the holes.

Tap the end of one axle into one of these holes, checking carefully to insure that the axle is at right angles (90") to the wheel, thus avoiding subsequent wheel wobble.



Insert the axle through the body of the cart, and attach a second wheel by the same process. Repeat the procedure with the remaining two wheels and axle, thus providing the cart with front and rear wheels.

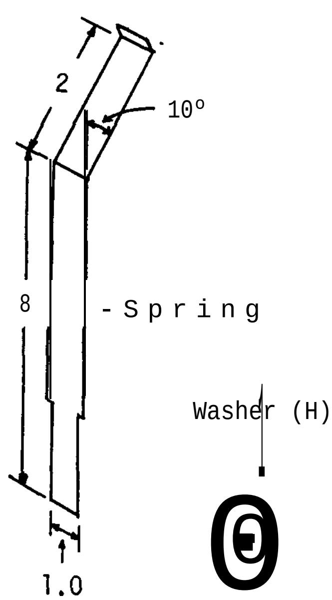
(3) Balloon Support



Cardboard (E)

Cut the strong cardboard (E) to a "T" shape as shown. Make a hole (diameter 1 cm) in the center of the top portion. Insert the support through the pair of slits closest to the end of the cart body. Use a rubber balloon (F) to provide acceleration for the cart [see Note (i)].

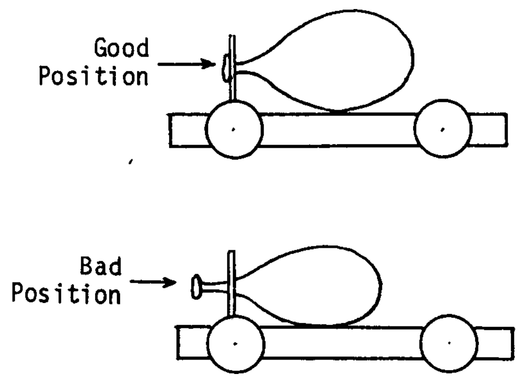
(4) Spring



Cut the packing case band (G) as indicated to make the spring. To facilitate the throwing of the washers (H) by the spring, bend the top end of the packing case band at an angle. Insert the spring through the remaining slits in the cart.

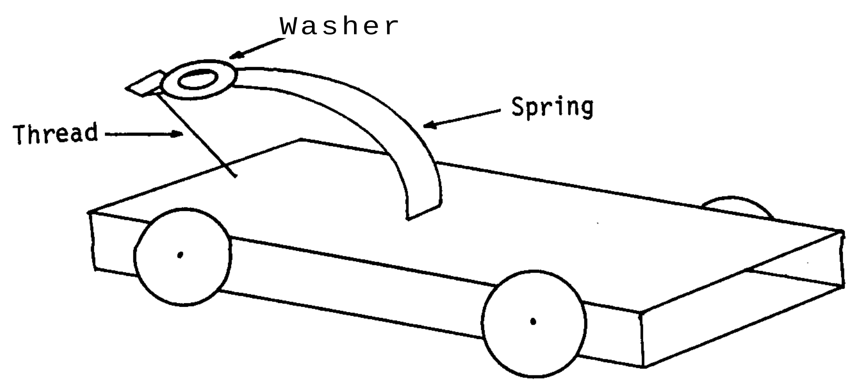
c. Notes

(i) Spherical balloons, as opposed to sausage-shaped ones, may be held in the balloon support (so long as the spring is removed), and are capable of accelerating the cart by the expulsion of air. The cart will be accelerated most efficiently if the open end of the balloon is held in such a way as to prevent it flopping from side to side with resultant dissipation of energy in all directions.



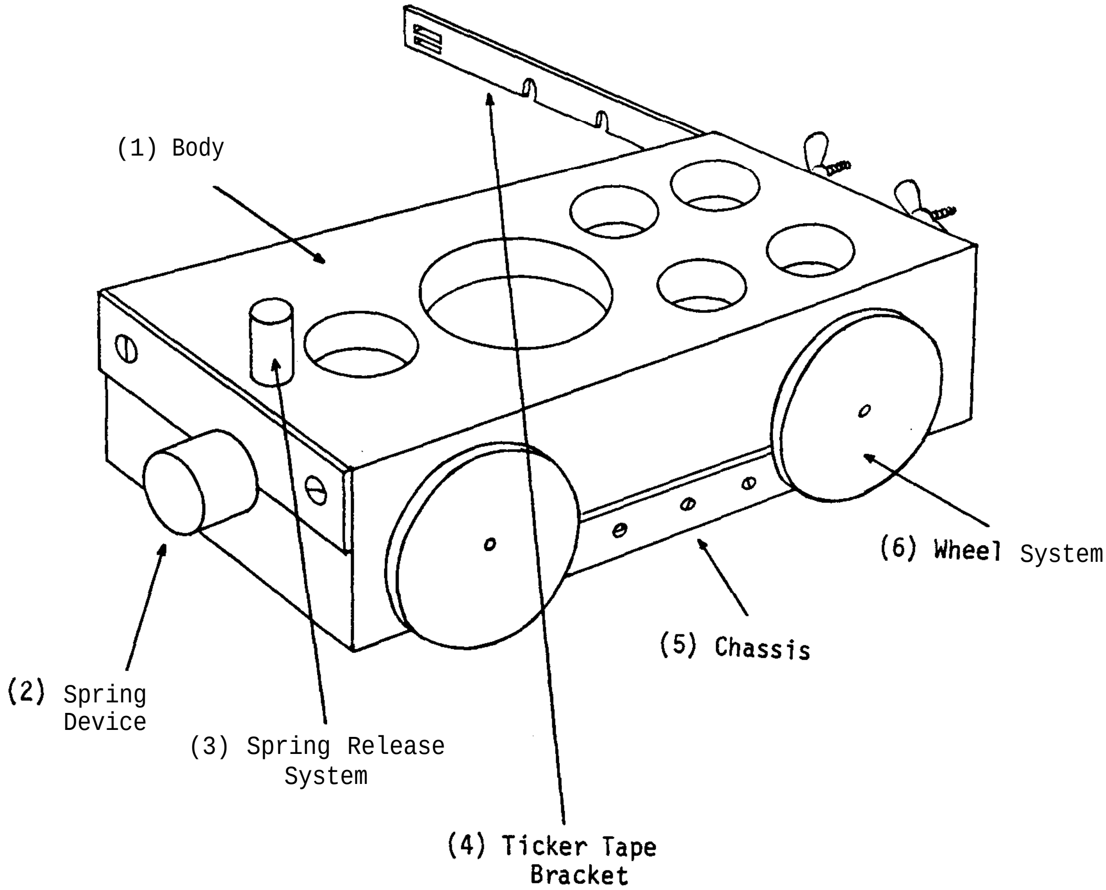
Not only does the cart motion illustrate action and reaction, but it also demonstrates accelerated motion due to a force. Once the balloon is deflated the acceleration ceases and the cart decelerates to a stop.

(ii) Take a length of strong thread (say 15 cm long), and tie the top end of the spring to the end of the cart in such a way that the top end of the spring is almost horizontal. Place a washer on the top end of the spring. If a burning



match is applied to the thread, the spring will be released and eject the washer forward, while the cart will be propelled backwards, thus offering another demonstration of action and reaction.

A2. Lightweight Cart ©



a. Materials Required

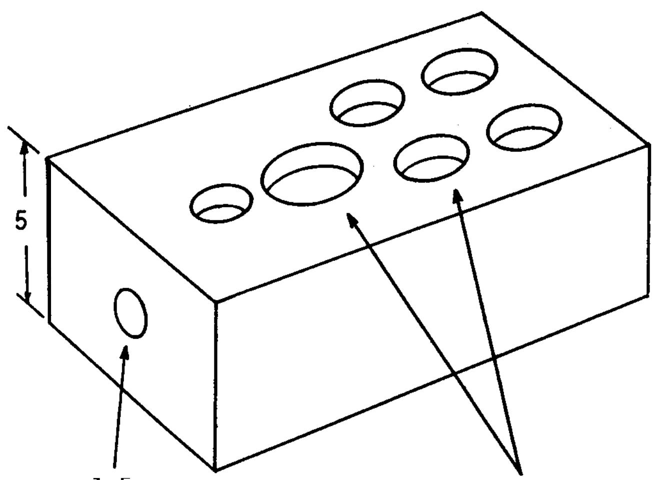
Components	Qu	Items Required	Dimensions
(1) Body	1	Wood (A)	15 cm x 6 cm x 5 cm
(2) Spring Device	1	Steel Wire (B)	80 cm long, 0.09 cm diameter
	1	Wood Dowel (C)	10 cm long, 1.2 cm diameter
	1	Rubber Stopper (D)	Approximately 2.5 cm diameter, and 1.5 cm long
	1	Screw (E)	1 cm long
(3) Spring Release System	1	Metal Plate (F)	6 cm x 1.5 cm x 0.05 cm

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 39-46.

	2	Screws (G)	1.5 cm long
	1	Wood Dowel (H)	3.5 cm long, 0.8 cm diameter
	1	Steel Wire (I)	#30, 3.5 cm long
(4) Ticker Tape Bracket	1	Aluminum Sheet (J)	15 cm x 1.2 cm x 0.05 cm
	2	Bolts (K)	0.2 cm diameter, 2 cm long
	2	Wing Nuts (L)	0.2 cm internal diameter
(5) Chassis	2	Packing Case Steel Bands (M)	Approximately 15 cm x 1.5 cm x 0.02 cm
(6) Wheel System	2	Wooden Spools (N)	Approximately 4 cm diameter
	2	Coat Hanger Wire (0)	10 cm long, 0.2 cm diameter
	1	Masking Tape (P)	1 cm wide
	--	Washers (Q)	--

b. Construction

(1) Body

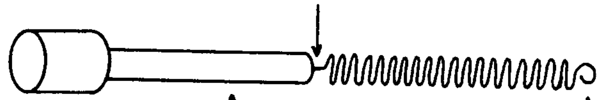


Bore a hole from the center of one end of wood (A) to the center of the other end, in order to accommodate a spring device. The diameter of the hole (1.5 cm) should be slightly larger than that of the spring (1.2 cm).

Bore holes into the top surface of the wood (A) to accomodate six masses (see I/C2), namely one 100 g mass (diameter 2.5 cm), four 200 g masses (diameter 2.5 cm) and one 500 g mass (diameter 4.0 cm). The holes should not be so deep as to cut into the horizontal hole for the spring.

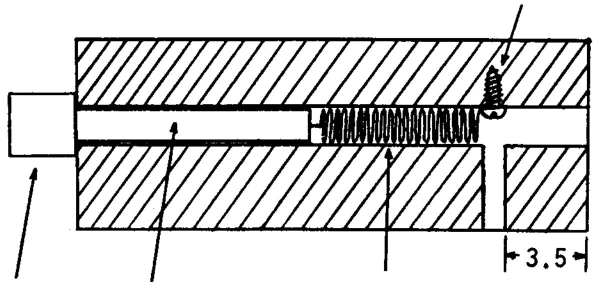
(2) Spring Device

Wind about 60 cm of the steel wire (B) into an open spring approximately 8.5 cm long,



1.2 cm in diameter, and with about 0.5 cm separation between each turn. (A method of winding the spring is described under I/C4). Straighten out one end of the spring into a spike and the other to a horizontal loop.

Attach the spring of one end of the wooden rod (C) by means of the spike and epoxy resin. Attach the rubber stopper (D) to the other end of the rod.

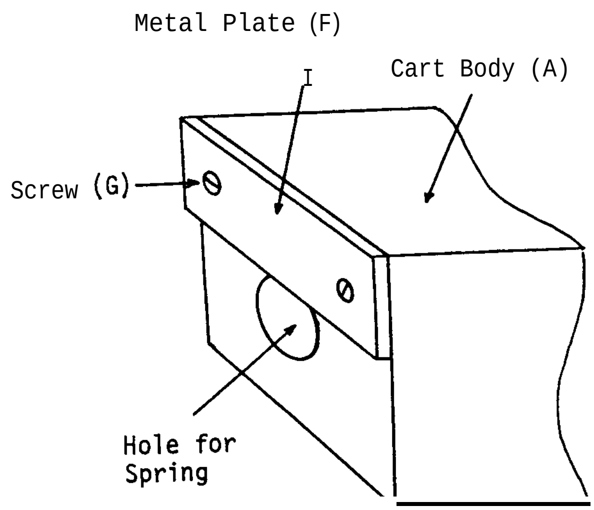


Cross Section
(Side view)

Bore a hole into the bottom of the cart body so that it meets the bore hole for the spring 3.5 cm from the end of the body. Then insert the screw (E) to anchor the loop end of the spring.

Ideally, two or three alternative springs of varying thickness and length should be made for trial purposes. The ultimate spring selected will be such that if two identical carts (one carrying three times its own weight) are placed end to end, and the spring device on one cart is then released, both carts will move apart a sufficient distance at uniform velocity to enable a measure of their initial separation velocities to be recorded.

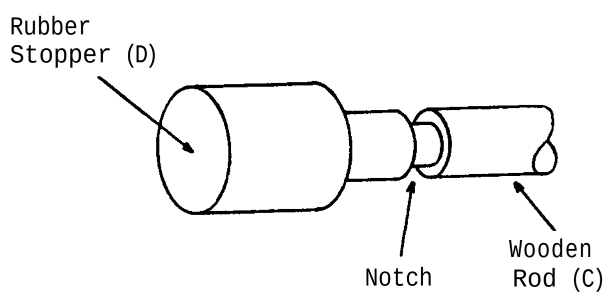
(3) Spring Release System

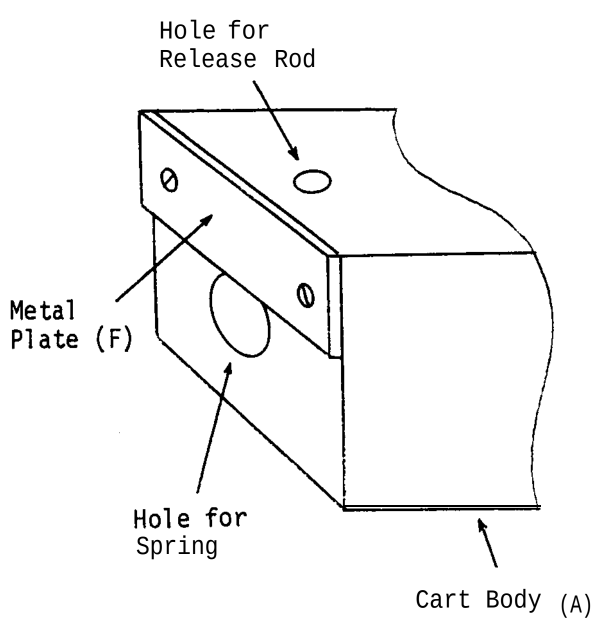


Fasten the metal plate (F) (brass, steel, etc.) onto the front of the cart with two screws (G) so as to just overlap the top of the hole for the spring.

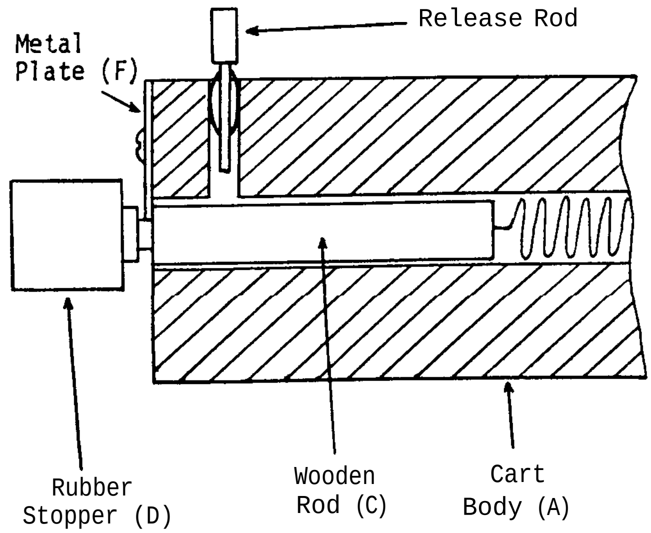
File a small notch around the wooden rod (C) on the spring device, close to the stopper.

It is thus possible to compress the spring into the hole, and hold it in position by means of the notch and metal plate.



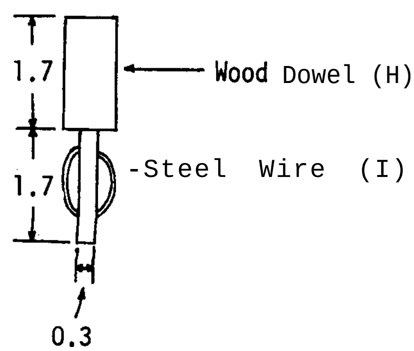


Bore a vertical hole (diameter 0.5 cm) into the top of the cart, near the front end, so that it meets the horizontal bore hole for the spring. The small wooden rod (H) (release rod) inserted into this hole, and pressed against the horizontal rod of the spring device itself, will release the spring from its state of compression. (The need to have the diameter of the spring bore hole slightly



Cross Section

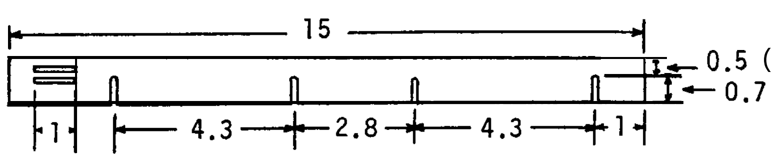
greater than that of the spring and attached rod should now be clear, for it is an essential requirement if the spring is to be released).



Release Rod

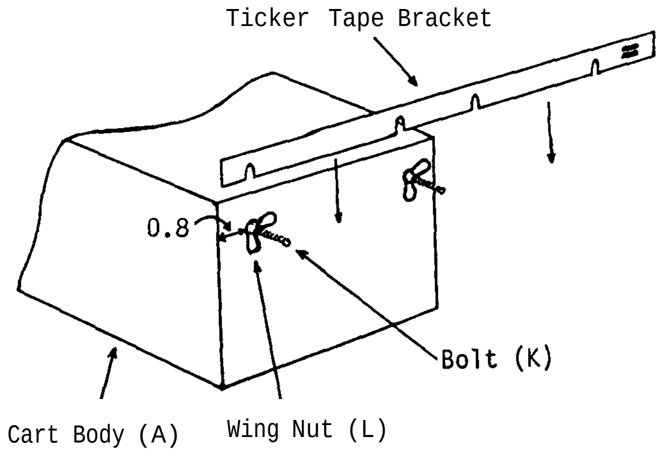
Cut the wood dowel (H) to the dimensions illustrated. The rod should be capable of moving freely in its bore hole, but at the same time it should not be so loose that it is easily lost. To prevent losing it, thread a thin piece of steel wire (I) through the rod so that it acts as a spring contact between the sides of the rod and the bore hole.

(4) Ticker Tape Bracket

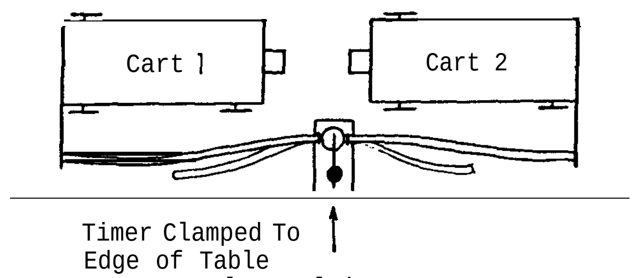


Sheet Metal (J)

Cut the ticker tape bracket from the sheet of metal (J) (brass, aluminum) which should be reasonably rigid, Make slits (0.1 cm wide) near the end to **take the ticker tape, and slots (0.35 cm wide) along the bottom** to enable the bracket to be attached to the bolts (K) at the

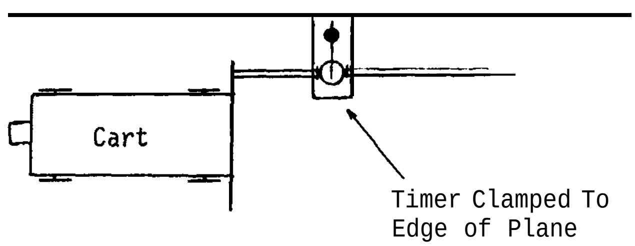


rear of the cart. Wing nuts (L) should be used to fasten the bracket in position.



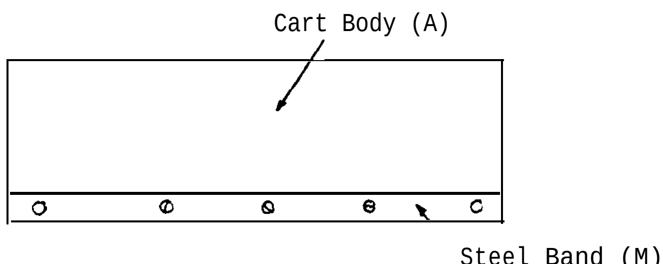
Mutual Repulsion

The purpose of the bracket is to insure that ticker tape attached to the cart is in line with the guides of the timer during any experiment, thus reducing friction. Two typical examples are illustrated when carts are mutually repulsed from one another, and when a single cart runs down an inclined plane.



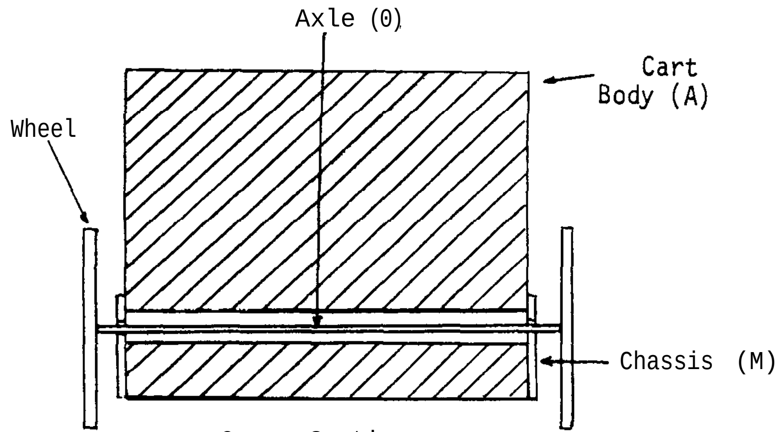
On Inclined Plane

(5) Chassis



Side View

Drill two horizontal holes (0.5 cm in diameter) through the cart body to permit passage of the front and rear axles. Make these holes 1.0 cm from each edge of the cart body (A). Cut the chassis from metal packing case bands (M). Drill five holes along the length of the

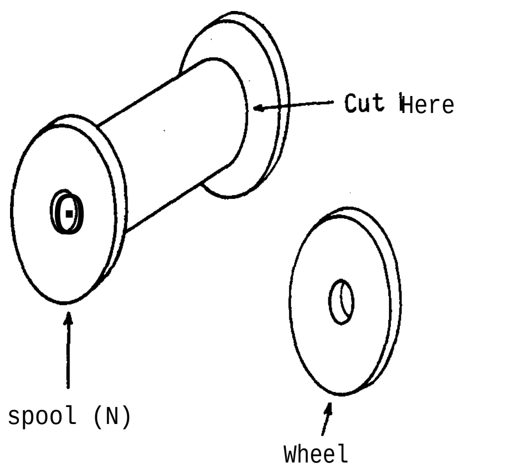


Cross Section

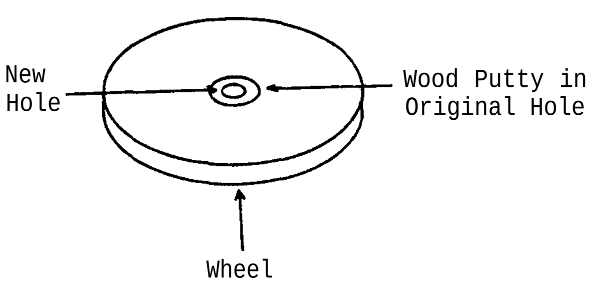
strip, two (diameter 0.3 cm) to coincide with the centers of the axle holes and three to enable the strip to be attached firmly to the body with screws.

The axles of the cart will in fact pivot in the chassis holes and not on the wooden holes through the cart, thus reducing friction.

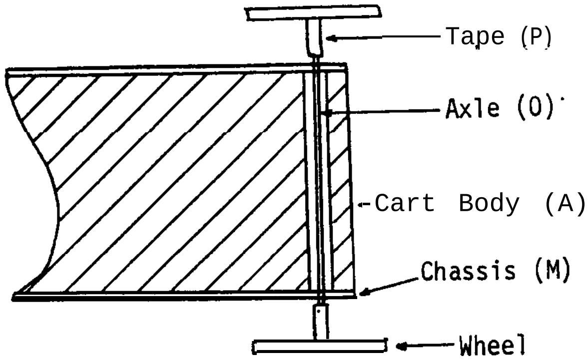
(6) Wheel System



Cut the four wheels from the ends of two wooden spools (N). Fill the spool holes with wood putty and allow the putty to dry hard.



Cut two lengths of wire (0) from wire coat hangers to serve as axles for the cart. Drill holes, slightly less than 0.2 cm in diameter, through the exact center of each wheel, and put a little epoxy resin in the holes.



Cross Section

Tap the end of one axle (O) into one of these holes, checking carefully to insure that the axle is at right angles to the wheel (thus avoiding subsequent wheel wobble).

Insert the axle through the body of the cart, and attach a second wheel by the same process. Repeat the procedure with the remaining two wheels and axle, thus providing the cart with front and rear wheels.

Make small spacers for all four wheels from masking tape (P), in each case wrapping it around the axle (next to the wheel) until it produces a cylindrical spacer 1 cm long and 0.5 cm in diameter.

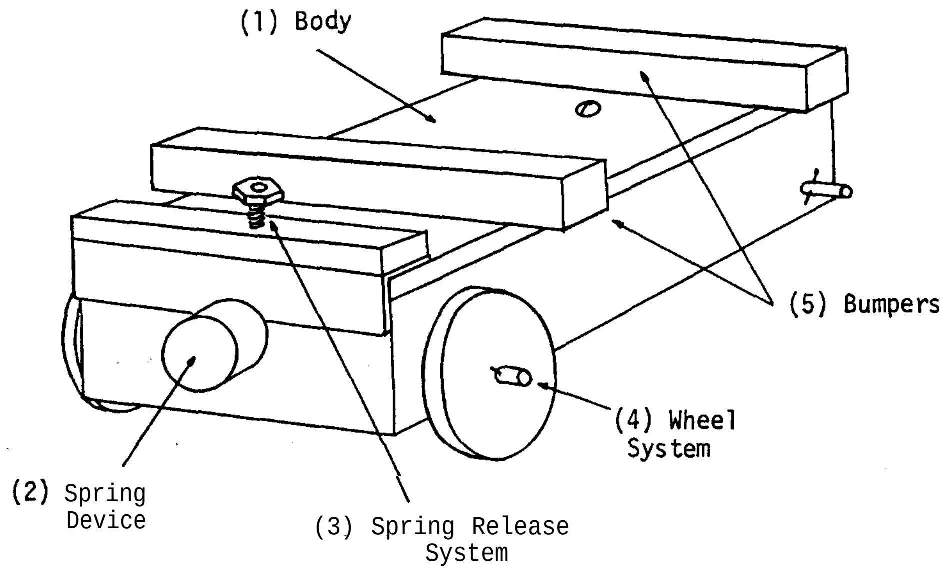
A little soap applied to each axle will serve as a lubricant between the axle and chassis contact points.

It is convenient to adjust the mass of the completed cart to the nearest 100 g. This may be done by shaving wood off the top or bottom surface of the body of the cart, or by adding washers to the body of the cart. In this case holes were drilled in the bottom of the cart, and washers (Q) fixed in the holes with screws. In this way the mass of the cart was adjusted to 400 g.

c. Notes

(i) This cart will inevitably be affected by friction more than a cart made with ball bearing wheels (III/A3). However, a full range of force and motion experiments may be performed with the cart if an inclined plane is used to compensate for friction affecting the cart. Simply adjust the inclination of the plane prior to any experiment so that the cart runs down the plane with constant velocity, the slope of the plane just compensating for the effect of friction.

A3. Heavyweight Cart

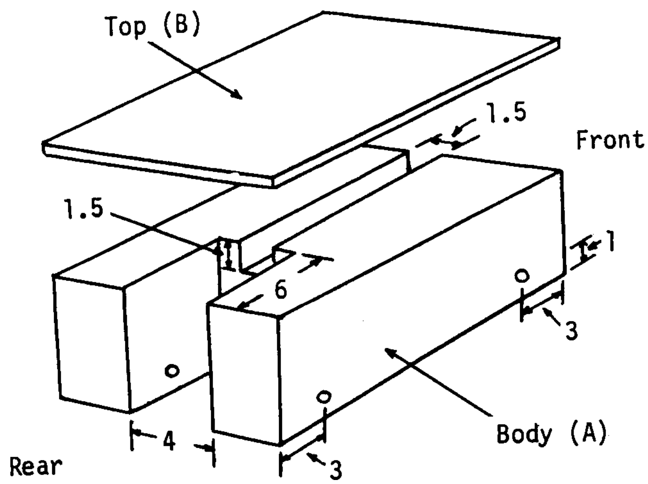


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	1	Wood (A)	30 cm x 8 cm x 4 cm
	1	Plywood (B)	30 cm x 8 cm x 0.5 cm
(2) Spring Device	1	Wooden Dowel (C)	16 cm long, 1.2 cm diameter
	1	Roll of Steel Wire (D)	0.09 cm diameter
	1	Rubber Stopper (E)	Approximately 2.5 cm diameter
	1	Screw (F)	4 cm long, 0.2 cm diameter
(3) Spring Release System	1	Aluminum Sheet (G)	8 cm x 3 cm x 0.05 cm
	1	Bolt (H)	3 cm long, 0.3 cm diameter
	2	Nuts (I)	0.3 cm internal diameter
	1	Wooden Strip (J)	8 cm x 2 cm x 0.5 cm
(4) Wheel System	3	Ball Bearing Wheels (K)	Approximately 5 cm diameter
	1	Wooden Dowel (L)	22 cm long, 0.5 cm diameter
	4	Nails (M)	Approximately 2 cm long
(5) Bumpers	2	Wood (N)	12 cm x 2 cm x 2 cm

b. Construction

(1) Body

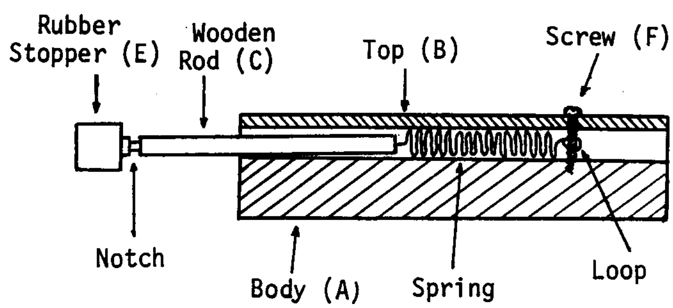


Cut the body of the cart from the piece of wood (A). Drill horizontal holes (diameter D.5 cm) close to the front and rear of the cart to hold the axles of the wheel system.

Using a saw and chisel, cut a horizontal slot in the top surface of the cart to contain the spring device, and a vertical slot in the rear of the cart to accommodate the rear wheel.

Use the piece of plywood (B) to make a top plate for the cart, and nail it onto the main body.

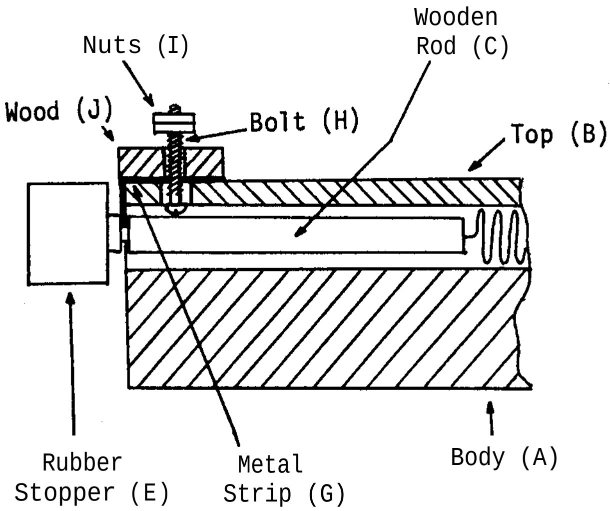
(2) Spring Device



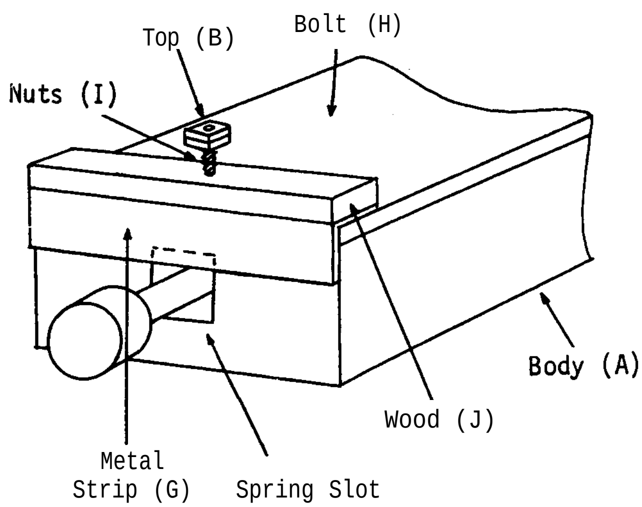
Cross Section

Make the spring device according to the instructions given for the previous cart (III/A2), but according to the dimensions indicated here. The spring, made from the steel wire (D), should be 1.2 cm in diameter and 16 cm long (excluding the spike and loop made on the end of the spring). Nail the rubber stopper (E) onto the end of the wooden rod (C), and make a notch (0.2 cm deep) around the rod about 0.5 cm from the end. Place the spring device in the appropriate slot in the cart, and anchor it in position by means of the screw (F) inserted through the top plate of the cart in such a way as to pass through the loop on the end of the spring.

(3) Spring Release System



Cross Section



Bend the sheet of aluminum (G) into an "L" shape (8 cm wide, 2 cm tall, with a base of 1 cm). Attach the sheet to the front of the cart so that the base of the sheet just overlaps the slot for the spring device. In this way the spring may be compressed and held in position by means of the metal sheet and the notch in the rod.

Use the bolt (H) and two appropriate nuts (I) to serve as a releasing device, and bore a hole through the metal sheet and top plate of the cart, 1 cm from the front, so as to expose the rod of the spring device.

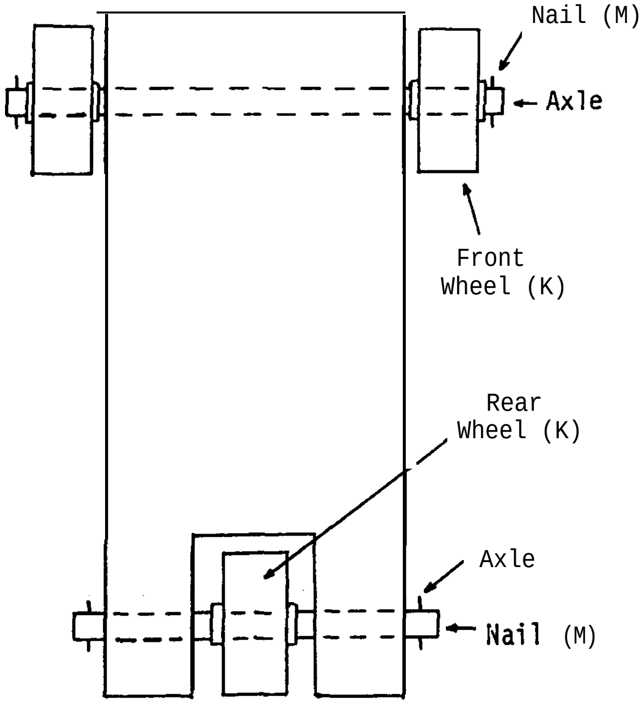
The diameter of the hole should be large enough to admit the head of the selected bolt.

Drill a hole through the middle of the wood strip (J). The diameter of the hole should be just large enough to admit the bolt (H), but not the head of the bolt. Place the bolt through the strip with the bolt head beneath the strip, such that it sits in the newly drilled hole in the body of the cart. Nail the strip in position on the front of the cart, and add the two locking nuts (I) to the end of the bolt.

(4) Wheel System

Three ball bearing wheels (K) will have to be purchased (possibly imported) for this cart. Cut two axles from the wooden dowel (L). Make the front axle 13 cm, and rear 9 cm long (both 0.5 cm in diameter in this instance). The diameter of the dowel should be the same as the internal diameter of the ball bearing wheels, thus providing a tight fit.

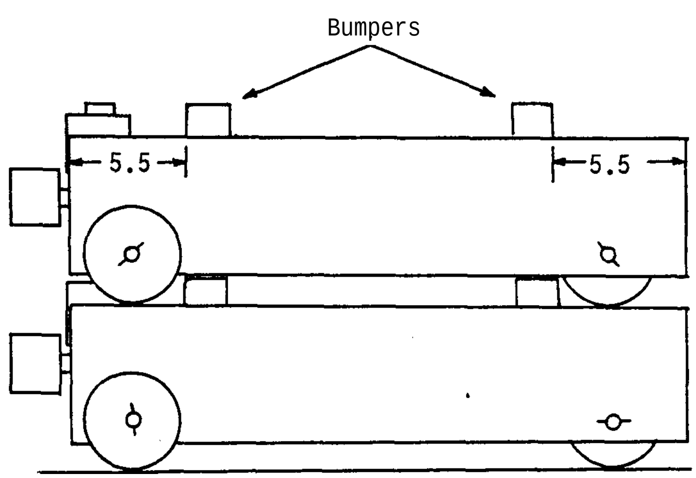
Pass the axles through the axle holes in the cart and fit the wheels appropriately on the axles. Take the four small nails (M), and drill holes of the same diameter as the nails through the axle ends. Insert the nails through the holes, thus securing the axles and wheels in position.



Top View

(5) Bumpers

Use the two strips of wood (N) as bumpers. Nail them in position on top of the cart in such a way that they will hold a second cart (placed on top of the first) firmly in position.



Side View

c. Notes

(i) The final weight of the cart will be of the order of 1,000 g. With ball bearing wheels this will not produce too much friction, while it will result in the moving cart having high momentum, and the cart will be little affected by what friction does exist.

(ii) A whole range of experiments related to force and motion will be found in many laboratory books, for example The Physical Science Study Committee, Laboratory Guide, (USA: D. C. Heath and Company, 1965).

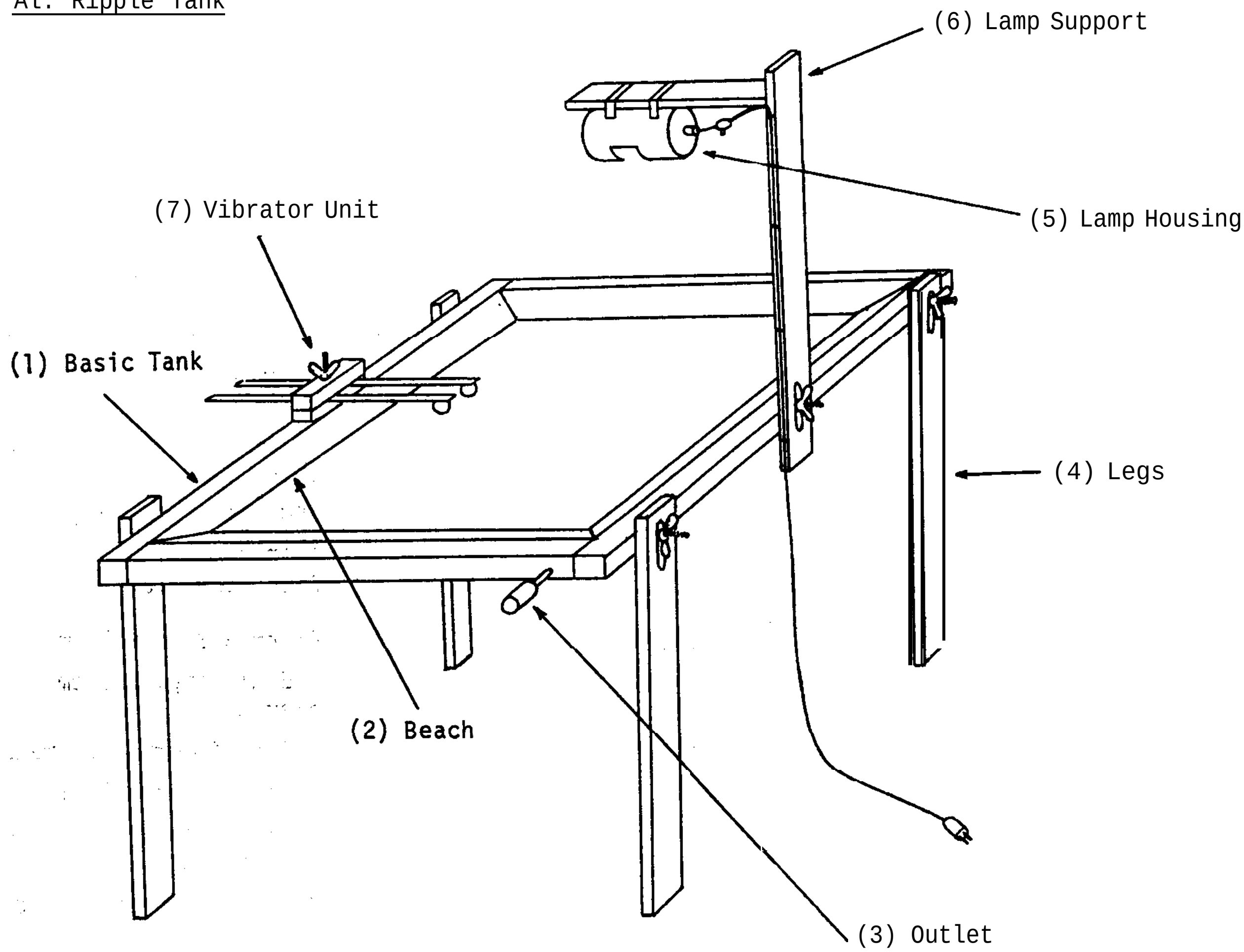
IV. WAVE MOTION APPARATUS

A. RIPPLE TANK APPARATUS

There are many ways of introducing wave motion to students, through observations of waves in water, heat radiation, acoustics, optics and electromagnetism. Each approach requires a different set of equipment. The materials here are limited to. presenting wave motion through the observation of waves on water, and the equipment is thus limited to ripple tanks and accessories.

A. RIPPLE TANK APPARATUS

A1. Ripple Tank©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Basic Tank	2	Wood (A)	60 cm x 3.5 cm x 3.5 cm
	2	Wood (B)	57 cm x 3.5 cm x 3.5 cm
	1	Glass Plate (C)	57 cm x 57 cm x 0.3 cm
	1	Rubber Based Cement (D)	--

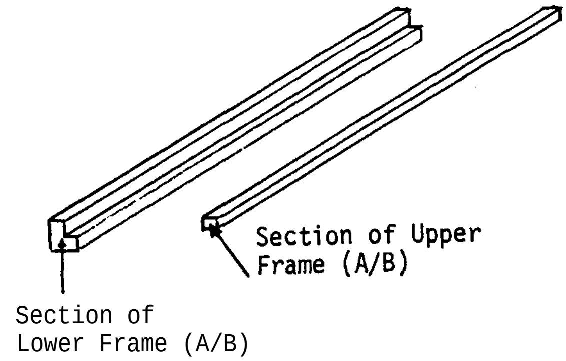
©From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center fo Educational Development Overseas 1972), pp 82-91.

(2) Beach	4	Soft Wood (E)	56.5 cm x 6 cm x 2 cm
	4	Brass Discs (F)	0.05 cm thick;3 cm diameter
(3) Outlet	1	Metal Tube (G)	5 cm long, 1 cm diameter
	1	Rubber Stopper (H)	2.5 cm diameter, 2.5 cm deep
(4) Legs	4	Wood (I)	60 cm x 3 cm x 2 cm
	4	Bolts (J)	3 cm long, 0.4 cm diameter
	4	Wing Nuts (K)	0.4 cm internal diameter
(5) Lamp Housing	1	Aluminum Sheet (L)	35 cm x 16 cm x 0.05 cm
	1	Plywood (M)	11 cm diameter, 0.4 cm thick
	1	Aluminum Sheet (N)	15 cm diameter, 0.05 cm thick
	1	Lamp (0)	100 watt, straight filament
	1	Electrical Socket (P)	Fits above lamp
(6) Lamp Support	1	Wood (Q)	65 cm x 3 cm x 2 cm
	1	Bolt (R)	4.5 cm long, 0.3 cm diameter
	1	Wing Nut (S)	0.3 cm internal diameter
	1	Wood (T)	48 cm x 2 cm x l cm
	1	Triangular Wood (U)	5 cmx 4 cm x 3 cm, and 1 cm thick
	1	Packing Case Steel Band (V)	7 cm x 0.5 cm x 0.02 cm
	2	Aluminum Strips (W)	1.5 cm x 0.6 cm x 0.02 cm
(7) Vibrator Unit	2	Packing Case Steel Bands (X)	30 cm x 1 cm x 0.05 cm
	2	Glass Marbles (Y)	1.5 cm diameter
	2	Wood (Z)	7 cm x 2 cm 21 cm
	1	Bolt (AA)	2.5 cm long, 0.4 cm diameter
	1	Wing Nut (BB)	0.4 cm internal diameter

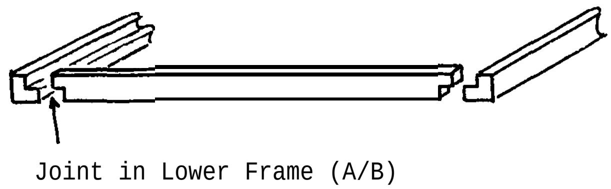
b. Construction

(1) Basic Tank

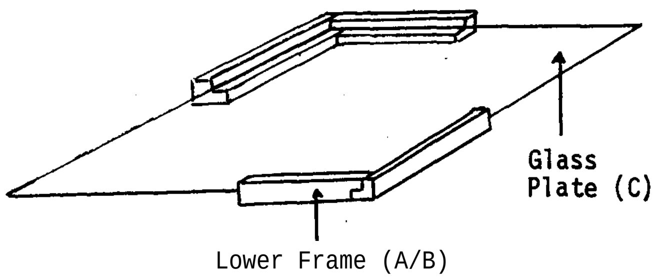
Out of each of the side wood strips (A and B) cut a single length approximately 2.0 cmx 2.0 cm, (A small circular



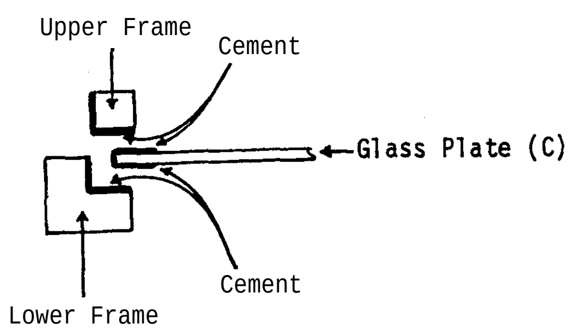
saw is useful in performing this task). You now have four large pieces of wood to make the lower frame, and four small pieces to make the upper frame.



The end pieces of the shorter lengths for the lower frame are cut (as illustrated) so that they may be firmly joined together with wood cement.

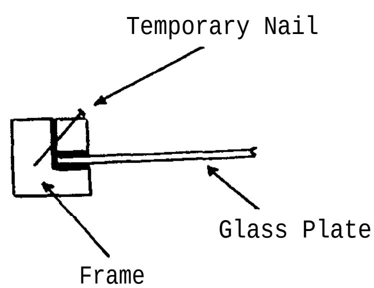


Set the glass plate (C) on the ledge of the lower frame. Cover the edges of the glass, and the inner edges of the lower and upper frame with a waterproof cement (D) as illustrated. An asphalt or rubber based cement is ideal. Set the glass on the ledge of the lower frame, and hold it in position by placing the upper frame on top of it.



Cross Section of Frame

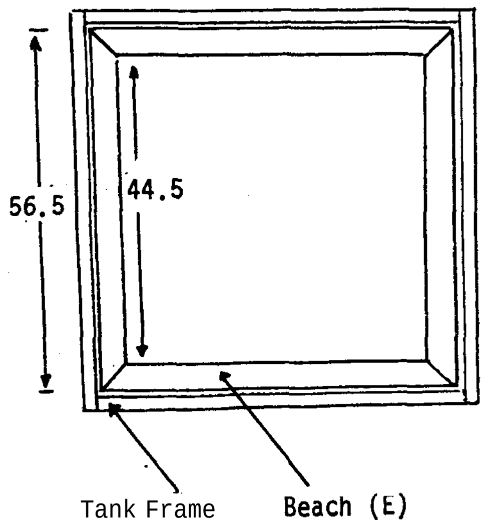
The whole frame may be held together by clamps, or nails, tacked temporarily through the two frames, until the cement is dry.



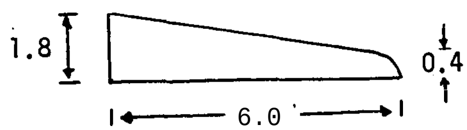
Cross Section of Frame

You now have a basic tank with an inner and outer frame insuring the tank is leak proof.

(2) Beach



Plan of Frame and Beach



The beach is any device which will cut out unwanted reflection from the sides of the tank. One of the most effective, and durable of beaches is made from soft pine wood (packing case material). Make the beach rather like a picture frame from the softwood (E) so that it sits on the glass surface of the tank, and fits snugly within the upper frame.

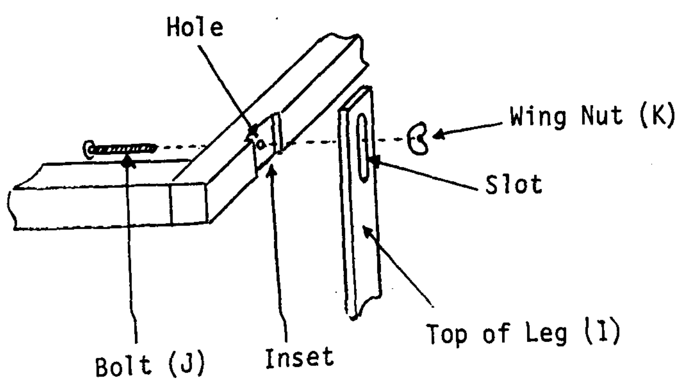
The most important aspect of the beach is the angle of the surface as it slopes downward from its outer to inner edge. The dimensions of a cross section to cope with water depths varying from 0.5 cm to 1.5 cm is illustrated.

Smooth the surface of the beach with fine sandpaper (leaving a smooth, but porous, surface), but do not varnish. Wetting the surface of the beach at the commencement of a series of experiments makes the damping of the waves most effective.

may be assisted by tilting the tank towards the corner. The bottom edge of the outlet hole should be at the same level as the top surface of the glass (or just a little below),

Seal the metal tube (G) into the horizontal hole with a waterproof cement. Bore a hole (0.9 cm diameter) partway into the rubber stopper (H) using an electric drill (not a cork borer). Fit the stopper on the tube, thus controlling the outflow of water.

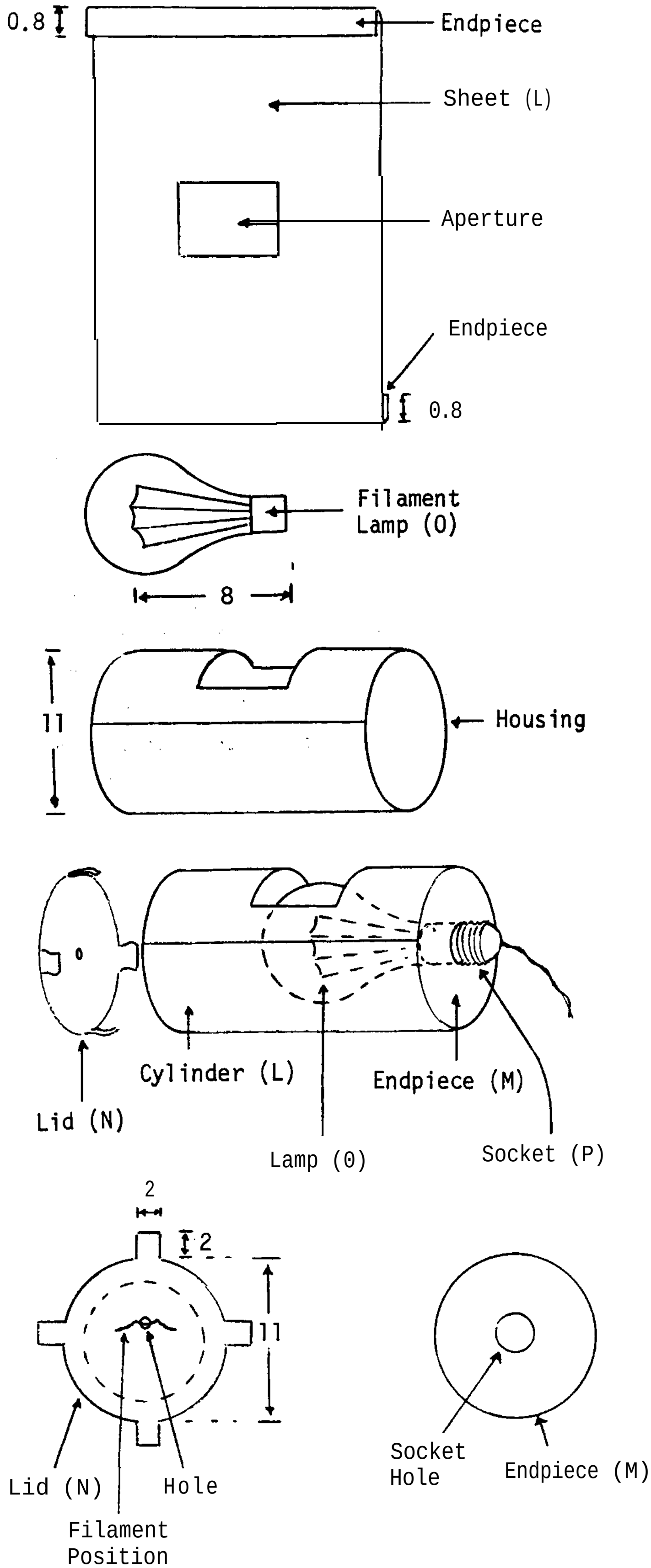
(4) Legs



Drill and chisel a slot (2 cm x 0.5 cm) in the top of each of the four wood pieces (I) to make adjustment slots for the legs. Make four insets (0.3 cm deep) in the frame to hold the legs firmly in a vertical position. Then, drill a horizontal hole (0.4 cm diameter) through the lower part of the outer frame (that is beneath the level of the glass) at the middle of each inset. Attach each leg to the frame with a bolt (J) passed through the hole in the frame and the slot in the leg. Fasten the bolt and leg firmly in position with a wing nut (K).

(5) Lamp Housing

The size of the lamp housing will be dependent on the size of the contained lamp. In this case the lamp (0) utilized was 8 cm from the socket to

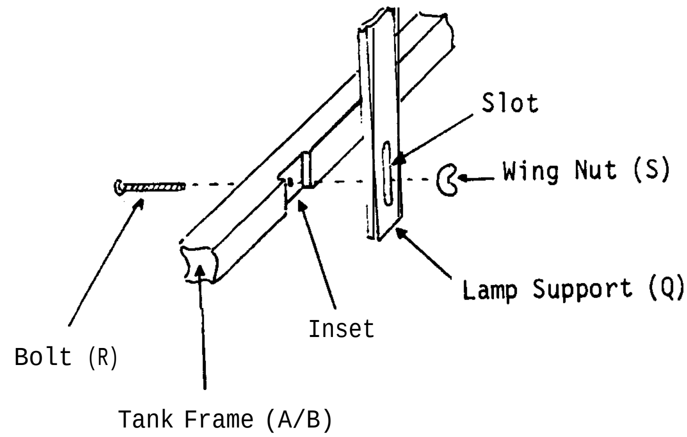


to filament. Ideally the filament should be a straight line, but a slightly bent filament such as that illustrated will serve the same purpose.

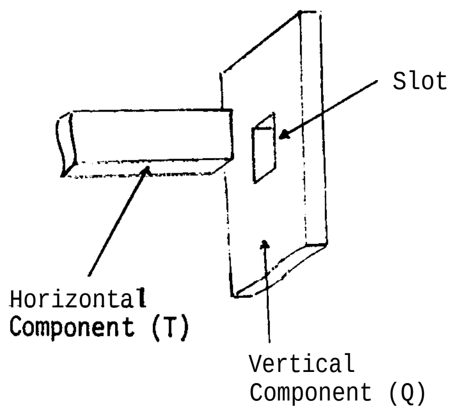
To make the housing for the above lamp take a sheet of aluminum (L) and cut an aperture (5 cm x 5 cm) from its center. Roll the sheet into a cylindrical shape, and hold it in position. by means of bent end pieces.

Attach the hardboard or plywood endpiece (M) to the base of the container with very small nails. Drill a central hole in the endpiece to facilitate the placement of the lamp (0) and electrical socket (P). Complete the housing by making a lid out of aluminum sheet (N). Drill a small hole (0.2 cm diameter) in the lid, such that it is in line with the filament.

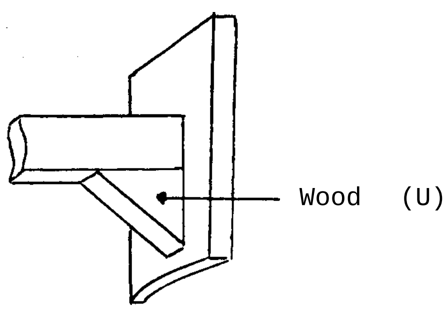
(6) Lamp Support

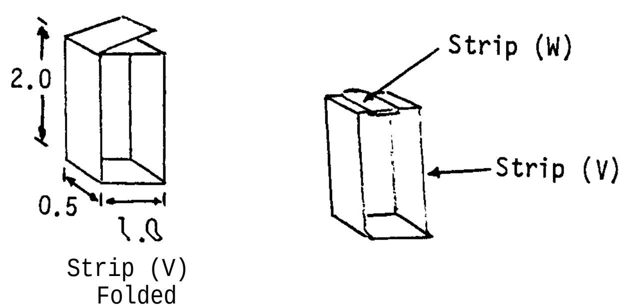


The vertical component of the lamp support is made, and attached to the ripple tank, in very much the same way as the legs. Drill and chisel a slot (7 cm x 0.5 cm) near to the bottom of end wood (Q) to permit adjustment. Attach the support to the ripple tank frame with bolt (R) passed through the lower part of the frame, and held in position by wing nut (S).

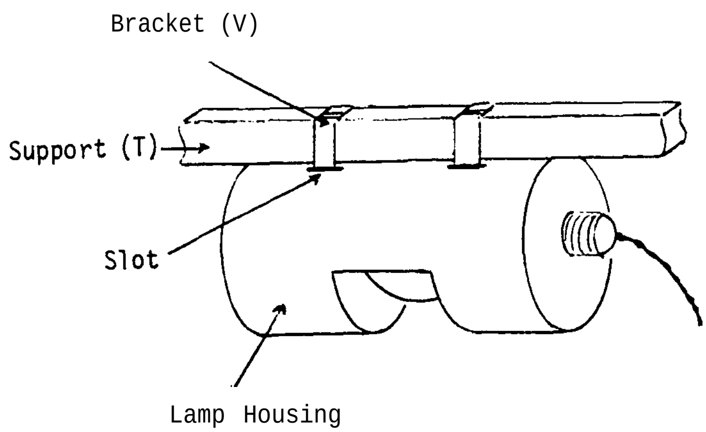


Cut a rectangular slot (2 cm x 1 cm) in the top of wood (Q) to take the horizontal component, wood (T). Fasten the two firmly together with wood cement. Glue a triangular piece of wood (U) between the two components to make a stronger junction.



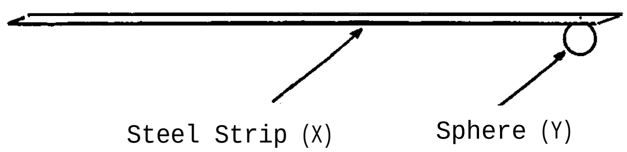


In order to attach the lamp housing to the horizontal components of the support make two brackets from steel strips (V) as illustrated. Cut four horizontal slots in the upper part of the lamp housing and

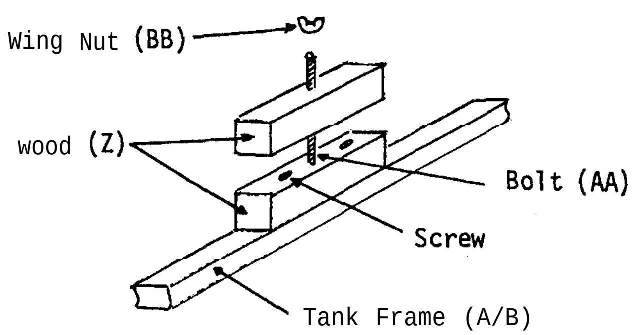


pass the steel strips through. Fasten the loose ends of the brackets together with folded pieces of aluminum (W). Then slide the brackets over the lamp support.

(7) Vibrator Unit



The steel strips (X), or stiff coat hanger wire, will serve as the arms of the vibrator. Attach a glass sphere (Y) to the end of each arm using epoxy resin.

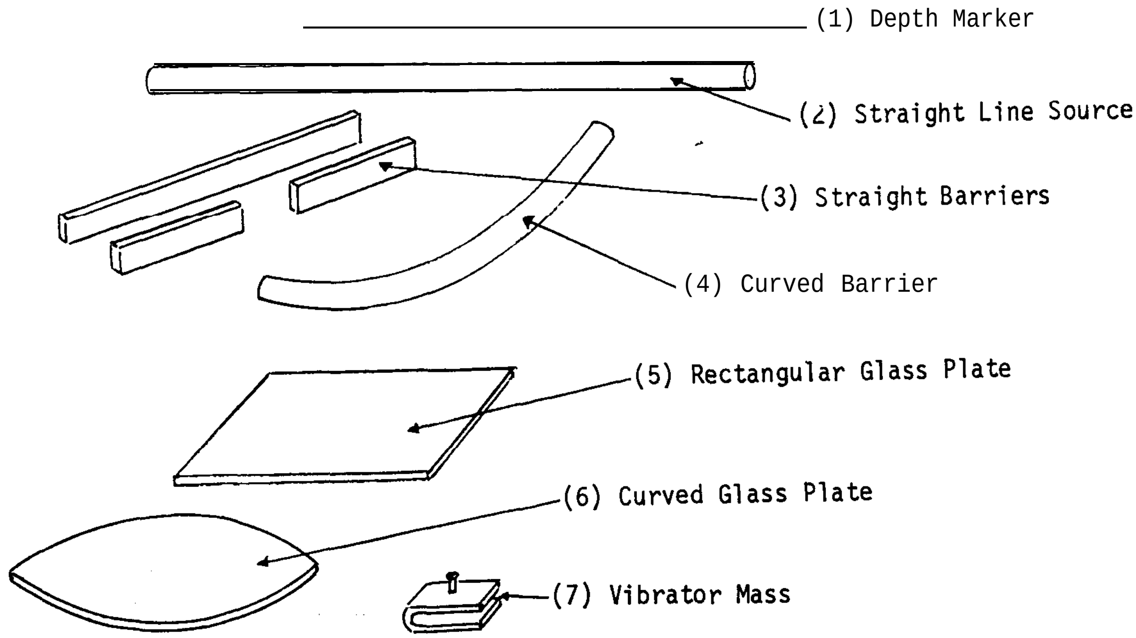


Make the vibrator clamp from two strips of wood (Z). Drill a hole (0.4 cm diameter) through the lower strip, and then attach the strip to the frame with two screws. Set the top strip on top of the first, and fasten it in position with the bolt (AA) and wing nut (BB). The vibrator arms may now be clamped firmly between the strips of the clamp, being held at the middle of the arms. This insures the maximum possible period of vibration.

c.Notes

(i) With the help of the Ripple Tank Accessories (IV/AZ) it is possible to observe the phenomena of reflection, refraction, interference and diffraction in waves created in the Ripple Tank.

AZ. Ripple Tank Accessories ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Depth Marker	1	Coat Hanger Wire (A)	10 cm long
(2) Straight Line Source	1	Wooden Dowel (B)	40 cm long, 2 cm diameter
	2	Nails (C)	15 cm long approximately
(3) Straight Barriers	1	Wood (D)	40 cm x 2.5 cm x 1 cm
	1	Wood (E)	15 cm x 2.5 cm x 1 cm
	2	Wood (F)	10 cm x 2.5 cm x 1 cm
	1	Wood (G)	5 cm x 2.5 cm x 1 cm
(4) Curved Barrier	1	Hose Pipe with Smooth Surface (H)	55 cm long, 2 cm diameter
(5) Rectangular Plate	2	Glass Sheets (I)	25 cm x 15 cm x 0.4 cm
(6) Curved Glass Plate	2	Glass Sheets (J)	25 cm x 15 cm x 0.4 cm

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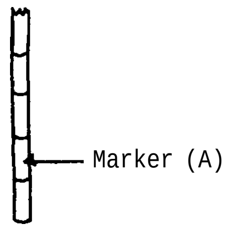
(7) Vibrator Mass	1	Iron Bar (K)	11 cm x 2 cm x 0.3 cm
	1	Bolt (L)	0.2 cm diameter, 1 cm long

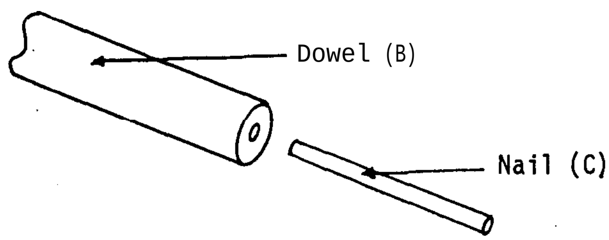
b. Construction

(1) Depth Marker



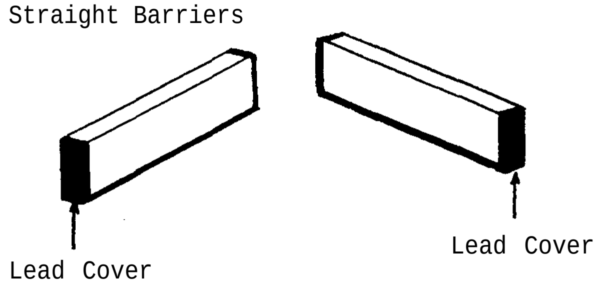
Mark off the end of wire (A) in half centimeter intervals (0-2 cm). The marker may then be used to determine the depth of the water at the four corners of the ripple tank, and makes the levelling of the tank simpler.

(2) Straight Line Source



Bore holes into both ends of the wooden dowel (B) and insert long nails (C) into the holes to prevent the rod from floating in the ripple tank.

(3) Straight Barriers



Nail thin strips of lead along the sides and base of the pieces of wood (D, E, F and G) to prevent them from floating in the ripple tank. The weighted pieces serve as suitable barriers.

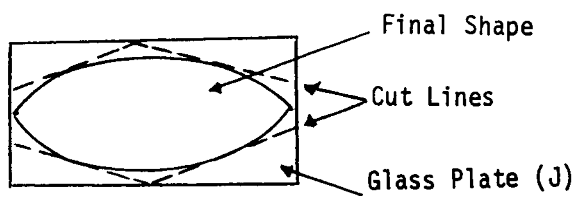
(4) Curved Barrier

A smooth surfaced hose pipe (H) serves as a suitable curved barrier. The pipe may be curved into any desired arc.

(5) Rectangular Plate

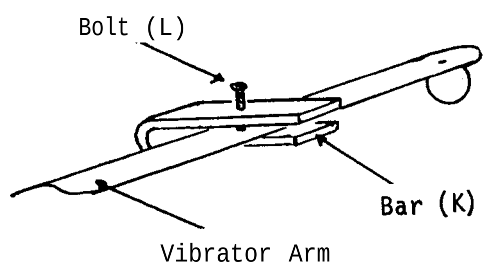
Take a sheet of glass (0.4 cm thick) and mark out two sections (each 25 cm x 15 cm x 0.4 cm) with a glass cutter. Break the glass along the marks by hand, The two newly produced sheets (I) may be set one on top of the other in water, thus creating a plate of thickness 0.8 cm.

(6) Curved Glass Plate



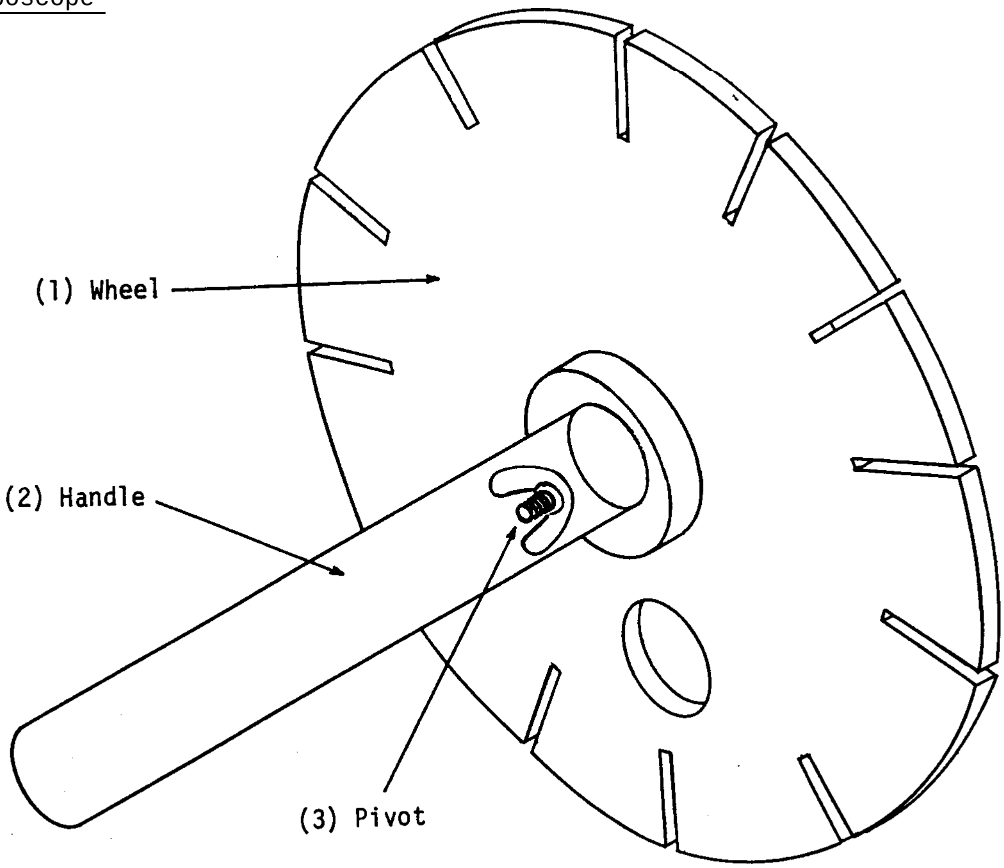
Scratch guidelines on the glass plates (J) in the shape of a parallelogram. Cut along the lines with a glass cutter, and break the glass along the lines. Grind down the shape to a curve, as indicated, with the help of a sandstone. The two plates may be used one on top of the other in the ripple tank, making a plate of thickness 0.8 cm.

(7) Vibrator Mass



The soft iron bar (K) should weigh approximately 50 g. Place the bar in a strong clamp, and use a hammer to bend it in half so that it becomes two parallel bars about 0.3 cm apart. Drill a hole (0.2 cm diameter) in the middle of the top bar, and make a thread (0.2 cm diameter) in the hole. Screw bolt (L) into the hole thus making it possible to clamp the bar onto the ripple tank's vibrator arm.

A3. Stroboscope ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Wheel	1	Hardboard (A)	25 cm diameter, 0.3 cm thick
(2) Handle	1	Wooden Dowel (B)	25 cm long, 2 cm diameter
(3) Pivot	1	Bolt (C)	4.5 cm long, 0.4 cm diameter
	1	Wing Nut (D)	0.4 cm internal diameter
	1	Nut (E)	0.4 cm internal diameter
	1	Wood (F)	3 cm diameter, 1.5 cm thick

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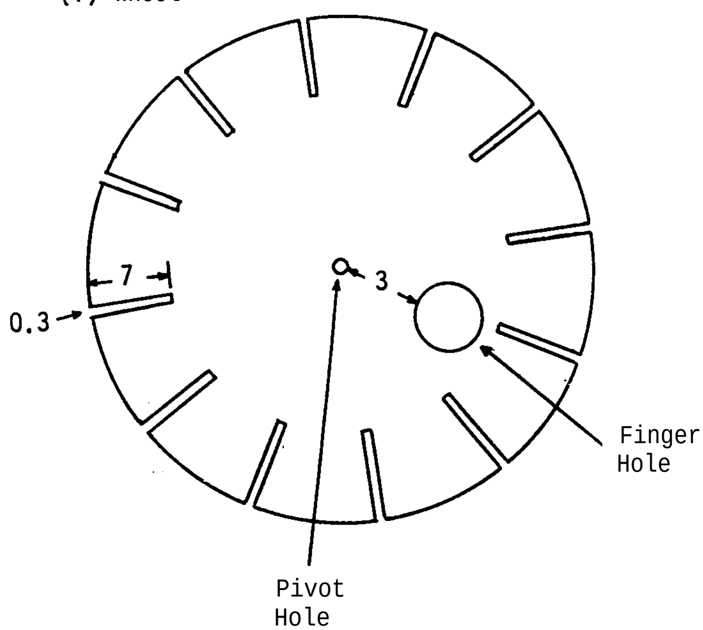
(1) Wheel

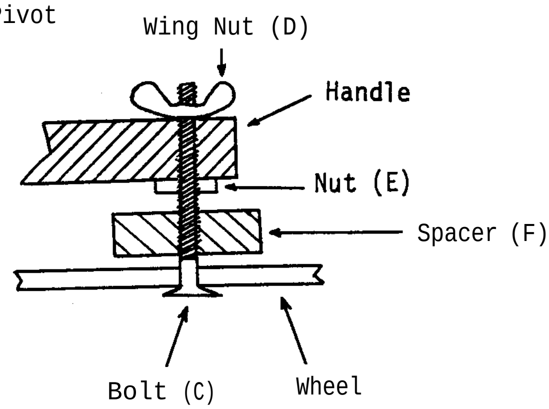


Cut the stroboscope wheel from the piece of hardboard (A). Make.12 equally spaced slits in the perimeter of the wheel. Drill a finger hole (2 cm diameter) at a distance of 3 cm from the center of the wheel, and a pivot hole (0.5 cm diameter) at the center of the wheel.

(2) Handle

The handle is simply a wooden dowel (B). Drill a hole (0.4 cm diameter) through one end of the handle to take the pivot bolt (C).

(3) Pivot



Detail
(Cross-section)

Use the bolt (C) to serve as the pivot for the wheel. Insert this through the wheel, the spacer (F), a locking nut (E) and the handle (B). Use the locking nut (E) and the wing nut (D) to hold the handle in a fixed position on the pivot,

c. Notes

(i) If the components of a moving body repeatedly take up fixed positions at regular intervals (e.g., vibrating bodies, waves) it is possible to "stop" the motion by viewing it through the slits of the stroboscope, rotated at an appropriate speed.

V. THE MULTIPURPOSE SYRINGE

The purpose of this chapter is to illustrate some of the multiple uses to which a syringe may be applied. The syringe devices are therefore grouped according to the concepts they are intended to illustrate.

A. AIR PRESSURE APPARATUS

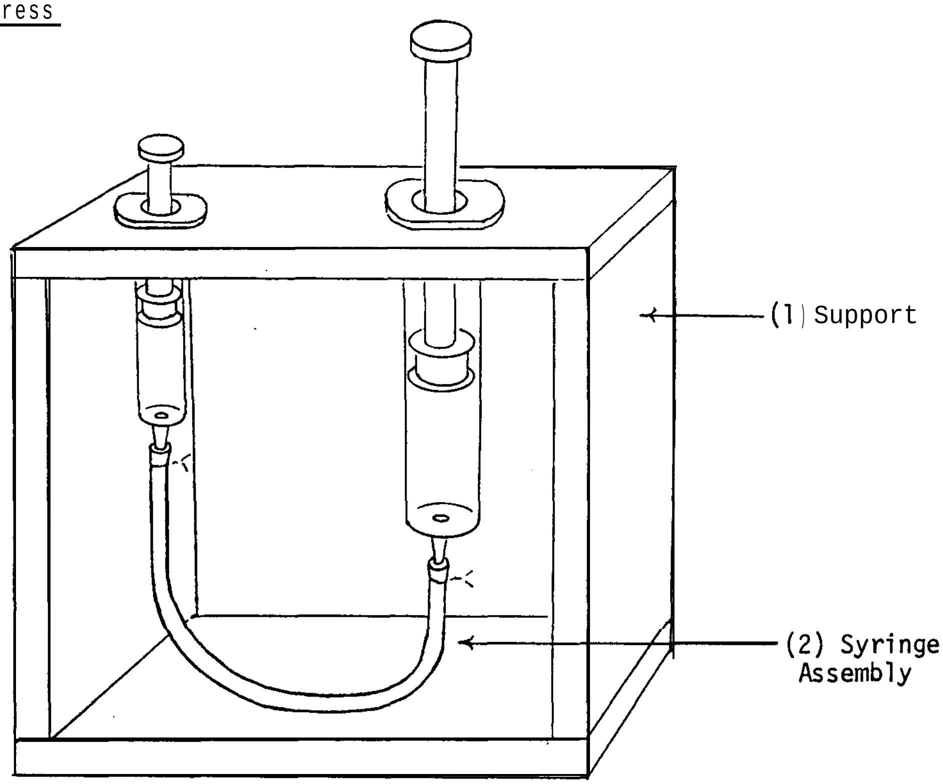
The devices in this section are all concerned with varying air pressure in the syringe.

B. SPECIFIC GRAVITY APPARATUS

The syringes in this section are used in one way or another to determine the specific gravity of solids and liquids.

A. AIR PRESSURE APPARATUS

Al. Hydraulic Press



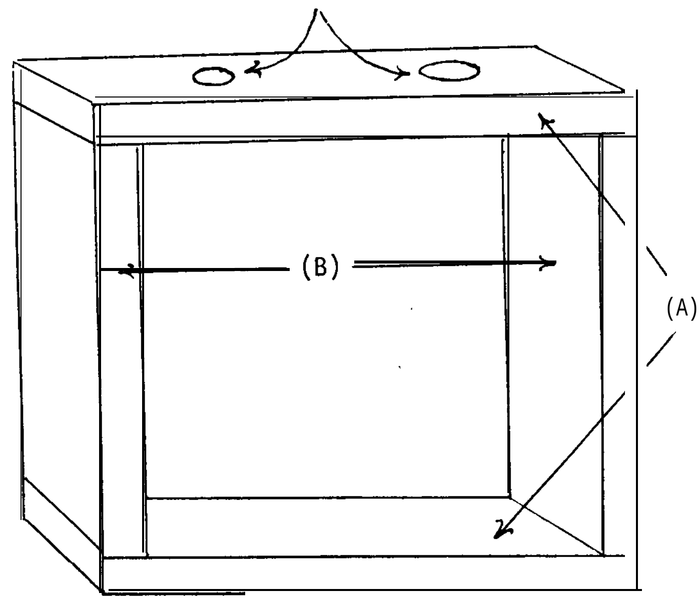
a. Materials Required

Components	QU	Items Required	Dimensions
(1) Support	2	Wood (A)	20 cm x 5 cm x 2 cm
	2	Wood (B)	17 cm x 5 cm x 2 cm
(2) Syringe Assembly	1	Plastic Disposable Syringe (C)	10 cc capacity
	1	Plastic Disposable Syringe (D)	60 cc capacity
	1	Rubber Tube (E)	20 cm long, 0.5 cm diameter
	2	Fine Wire (F)	5 cm long

b, Construction

(1) Support

Nail the two shorter pieces of wood (B) to the ends of one of the longer pieces (A) in upright positions. Before



nailing the last piece (A) into position across the top of the support, two holes must be drilled in it. These holes must be slightly larger in diameter than the barrels of the syringes used. Make these holes about 10 cm apart.

(2) Syringe Assembly

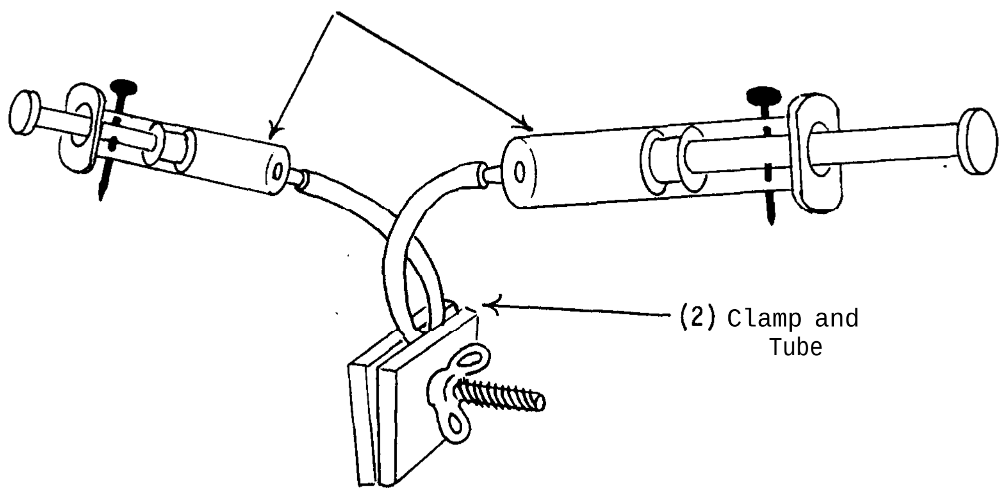
Attach one end of the rubber tube (E) to the nozzle of the larger syringe (D). Wrap one piece of wire (F) around this joint to seal it as tightly as possible. With-draw the plunger of this syringe halfway to fill it with water through the end of the rubber tube, Try to eliminate as many of the air bubbles from the syringe as possible,

Holding the free end of the rubber tube so that no water can escape, run the end of the tubing through. the hole in the support and put-the large syringe into position. Put the barrel only of the small syringe (C) into posi-tion, and connect the end of the rubber tubing to the nozzle. Again, use the wire (F) to make the junction tight. Push the plunger of the large syringe down until the water rises in the small syringe and is about to run over. Insert the plunger of the small syringe now and push down, and a minimum of a air should be trapped in the system.

C. Notes

(i) The lifting power of the hydraulic press may be felt by exerting a gentle downward pressure on each syringe simultaneously with both hands. The load on the smaller syringe will lift the plunger of the larger syringe, even when the load on the latter is felt to be greater than that on the smaller syringe.

AZ. Vacuum Apparatus

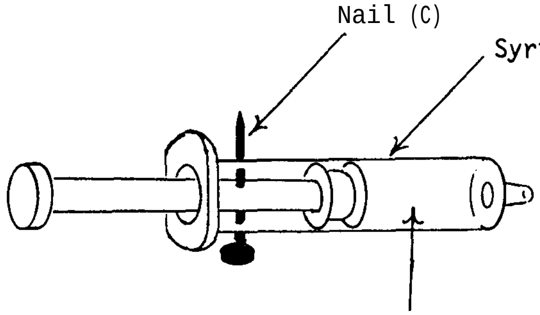


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Fixed Syringes	1	Plastic Disposable Syringe (A)	35 cc capacity
	1	Plastic Disposable Syringe (B)	10 cc capacity
	2	Nails (C)	4 cm long
(2) Clamp and Tube	1	Plastic Tube (D)	20 cm long, 0.5 cm diameter
	1	Screw Clamp (E)	CHEM/IV/A5

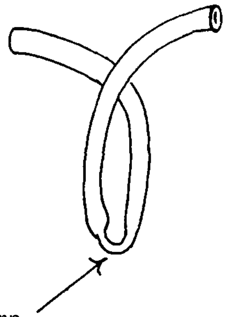
b, Construction

(1) Fixed Syringes



Use a drill of a slightly larger diameter than that of the nails (C) to carefully make holes through the barrel and plunger of the plastic syringe (A), When the nail (C) is inserted through these holes, the plunger should be held in a position such that the volume in the syringe is 25 cc. Similarly, prepare the second syringe (B) so that the volume is held at 5 cc capacity when the nail is in place.

(2) Clamp and Tube .



Connect the two syringes with the length of plastic tube (D). Be certain the connections between the nozzles and tubing are tight. Also, the tubing must be flexible enough to allow the clamp to close it off completely while, at the same time, it should be elastic enough not to collapse as pressure in the system becomes lower. The clamp (E) will close off air flow through the tube most easily when the tube is doubled over against itself.

c. Notes

(i) To use this piece of equipment to create a vacuumin, the larger syringe (A), first fix the volume of the air in the syringe (A) at 25 cc using the nail to hold the plunger in position. Connect the clamp and tubing to it. Depress the plunger in the smaller syringe (B) completely, then fasten the syringe to the tubing, and close the clamp. Now, open the clamp and withdraw the plunger in the smaller syringe. This will extract air from the larger syringe. Fix the plunger of the smaller syringe with the nail, and reclose the clamp. Remove the smaller syringe from the tubing.

The extraction procedure may be repeated five or six times in succession in order to produce very low pressures.

(ii) After one or more extractions, the reduced pressure in the large syringe may be determined by holding the syringe under water and removing the clamp from the tube. Water will rise in the syringe until the trapped air is once again at atmospheric pressure. Note the volume of the trapped air.

If

The volume of air finally trapped above water = V_2
The pressure of air finally trapped above water = P_2
(Where P_2 = atmospheric pressure)

And if

The volume of same mass of air prior to contraction = V_1
(Where V_1 = volume of syringe)
The pressure of same mass of air prior to contraction = P_1

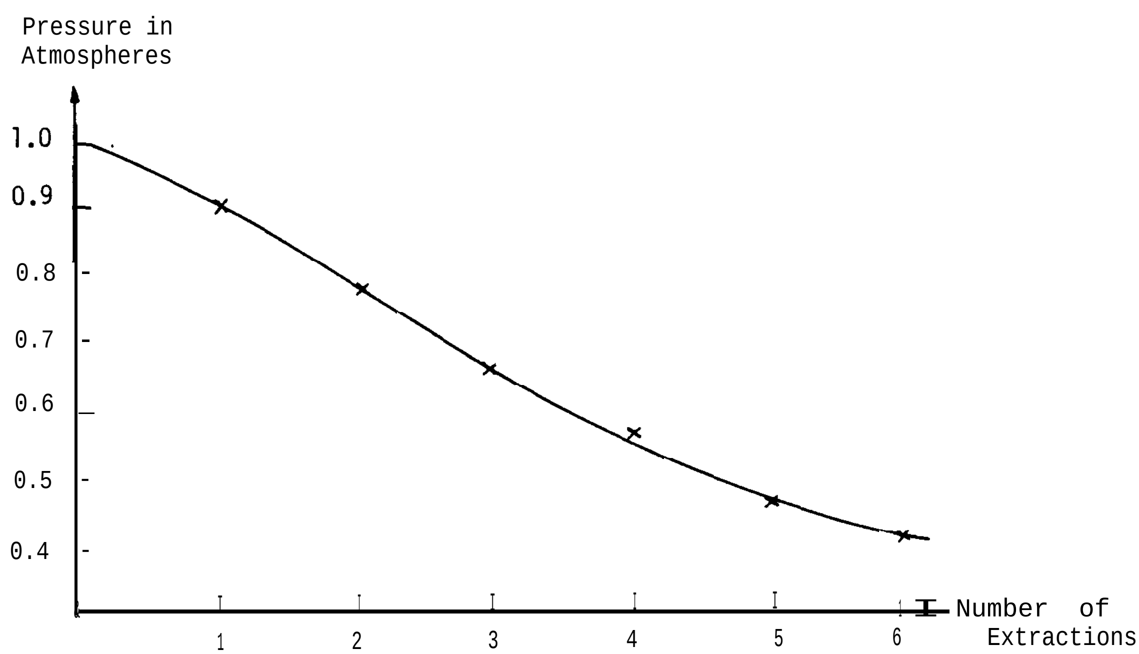
Then

The pressure of the vacuum created is given by

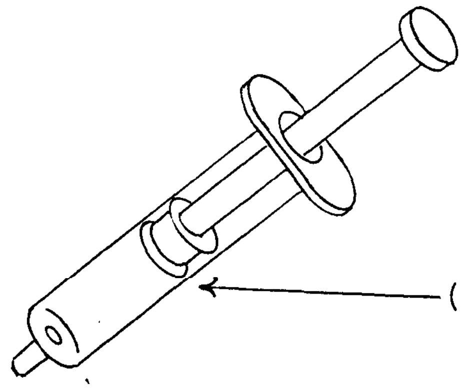
$$P_1 = \underline{P_2V_2}$$

(iii) In a typical experiment (results indicated below) five extractions reduced the pressure in the large syringe to 0.5 atmosphere pressure.

No. of Extractions	V_2 cc	V_1 cc	P_1 Atmospheres
1	25	23	0.92
2	25	19.5	0.78
3	25	16.5	0.66
4	25	14.5	0.58
5	25	12.0	0.48
6	25	10.5	0.42



A3. Elasticity Device



a, Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	Size can be variable

b. Construction

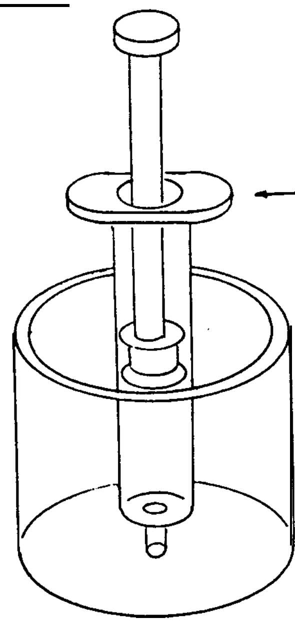
(1) Syringe

Place a finger over the air outlet to seal the air in the tube.

c, Notes

(i) With a sealed syringe, elasticity of air may be felt by pushing down or pulling out the plunger. In either case, if the syringe is airtight, the plunger will be pushed or pulled back to its original position by the air trapped in the syringe:

(ii) It is of interest to replace the air in the syringe by water in order to compare the elasticity of water with that of air, A4. Gas Expansion Device ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe Unit	1	Plastic Disposable Syringe (A)	Size can be variable
	2	Beakers (B)	Approximately 250 ml

b. Construction

(1) Syringe Unit

Any size syringe (A) may be used, but one approximately 10 - 15 cc in capacity is convenient, Fill one beaker (B) with hot water and the other with cold water.

c. Notes

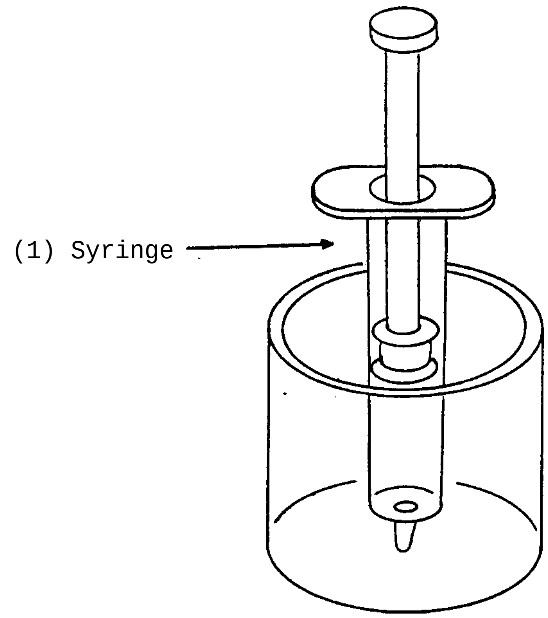
(i) After the syringe has been filled with suitable gas (e.g., air) it is placed in the cold water bath for several minutes. It is then removed, emptied of any water which may have entered through the open nozzle, adjusted to a volume of 5 or 10 cc, and placed in the hot water bath, As the gas expands, bubbles will leave the syringe. After the bubbling has ceased, remove the syringe and place

©From Andrew Farmer, "The Disposable Syringe: Additional Experiments," School Science Review, CLXXVIII (1970), pp 59-60.

it back in the cold water bath. As the gas contracts, water will enter the syringe, and the amount of water entering serves as a measure of the expansion of the gas. Quantitative data on gas expansion can be obtained by using the same gas and syringe and varying the temperature of the hot water bath, or by using the same syringe and hot water bath and varying the gases.

B. SPECIFIC GRAVITY APPARATUS

Bl. Volume Determinator



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	Size can be variable
	1	Beaker (B)	Approximately 250 ml

b. Construction

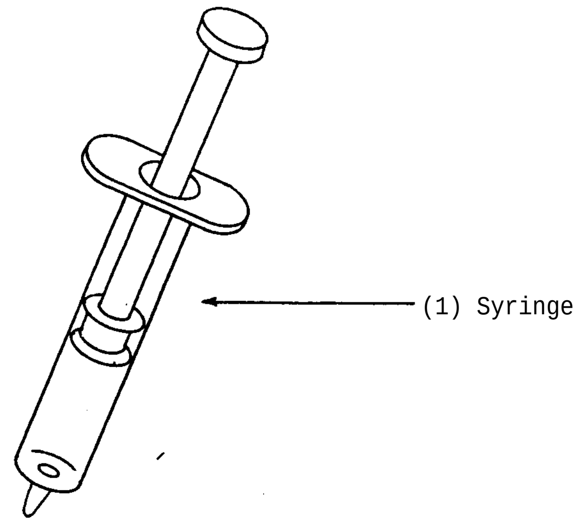
(1) Syringe

Choose a plastic, disposable syringe (A) with a barrel capacity large enough to hold the object whose volume is to be measured, Fill the beaker (B) about one half full of water.

C. Notes

(i) Use this apparatus by placing the object whose volume is to be measured into the syringe. Replace the plunger and depress it until it almost touches the object in the bottom of the syringe. Hold the syringe so that the end of it is under water in the beaker. Draw enough water into the syringe to cover the object by withdrawing the syringe plunger. Find the difference between the original syringe reading and the final syringe reading. This indicates the volume of water drawn into the syringe. Note the apparent volume of water in the syringe (that is the volume of the object and the water combined) and subtract from this the volume of water known to have been drawn into the syringe. The resultant va indicates the volume of the object.

B2. Specific Gravity Device



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	35 cc capacity

b. Construction

(1). Syringe

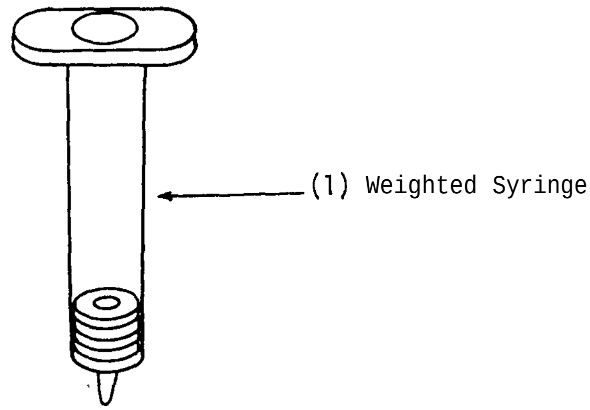
Use the syringe (A) with no modification except to remove the needle, as usual.

c. Notes.

(i) To determine the specific gravity of a liquid, simply draw up 25 cc of the liquid, and find the mass of the liquid plus syringe. Subtract the mass of the empty syringe from this total to find the mass of the liquid. Divide the mass of the liquid by 25 to obtain the specific gravity.

(ii) If the liquid should leak from the syringe, simply seal the nozzle of the syringe with a nail. Remember to add the mass of the nail into the calculations.

B3. Hydrometer



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Weighted Syringe	1	Plastic Syringe Barrel (A)	35 cc capacity
	6-8	Metal Washers (B)	Slightly less wide than the barrel

b. Construction

(1) Weighted Syringe

Place enough washers (B) in the syringe barrel (A) to cause it to sink to the 25 cc mark when placed in water. Seal the nozzle by heating it until it melts shut.

c. Notes

(i) For use as a hydrometer, the syringe barrel must be calibrated. Use a graduated cylinder (CHEM/III/B2) to make the calibrations. Note the water volume in the cylinder before and after the syringe barrel is placed in it. The difference of these two values indicates the volume of water displaced by the syringe. By this means it is possible to indicate a displacement value for each reading on th syringe. The following table was created for the syringe under test.

Scale on Syringe	Volume of Water Displacement
cc	cc
20	27.2
21	28.6
22	29.2
23	30.4
24	31.5
25	33.0
26	34.5
27	36.1
28	37.5
29	38.4
30	39.6

Weigh the syringe (and its washers), and then place it in the liquid whose density is to be determined.

'(ii)

If

V = The volume of liquid observed to be displaced

M · The mass of the syringe and washers

Then

M = The mass of liquid displaced

M/V = The density of the liquid displaced

VI. OPTICS APPARATUS

The apparatus in this section has been grouped according to the concepts, and are identified as follows:

A. GENERAL APPARATUS

This apparatus is for use in studying all aspects of optics whether this might be reflection and refraction, or interference and diffraction.

B. REFLECTION APPARATUS

This apparatus is sufficient for a simple study of reflection. The electroplated mirrors are preferable to brass mirrors described, although the latter will be found adequate for most purposes.

C. REFRACTION APPARATUS

Apparatus for the study of refraction using plastic prisms.

D. LENS APPARATUS

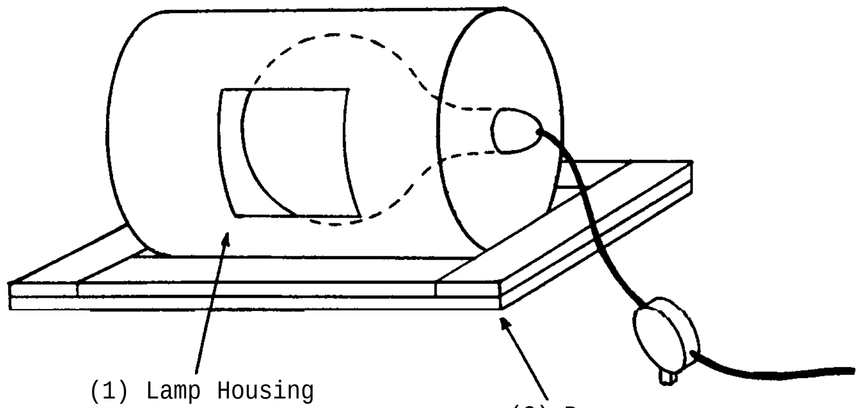
Apparatus to enable a study of the properties of lenses.

E. DIFFRACTION AND INTERFERENCE APPARATUS

A study of the basic phenomena of interference and diffraction is possible with this apparatus, using simple slits, holes and thin films.

A. GENERAL APPARATUS

Al. Light Source ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Lamp Housing	1	Ripple Tank, Lamp Housing (A)	IV/Al, Component (5)
(2) Base	1	Plywood (B)	21 cm x 11 cm x 0.5 cm
	2	Wood Strips (C)	16 cm x 2.5 cm x 1 cm
	2	Wood Strips (D)	11 cm x 2.5 cm x 1 cm

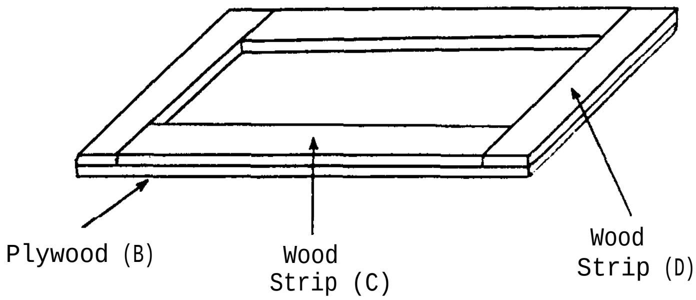
b. Construction

(1) Lamp Housing

This lamp housing (A) is precisely the same as that designed for the ripple tank (IV/Al). All that is added is a base.

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 19/2), p 98.

(2) Base

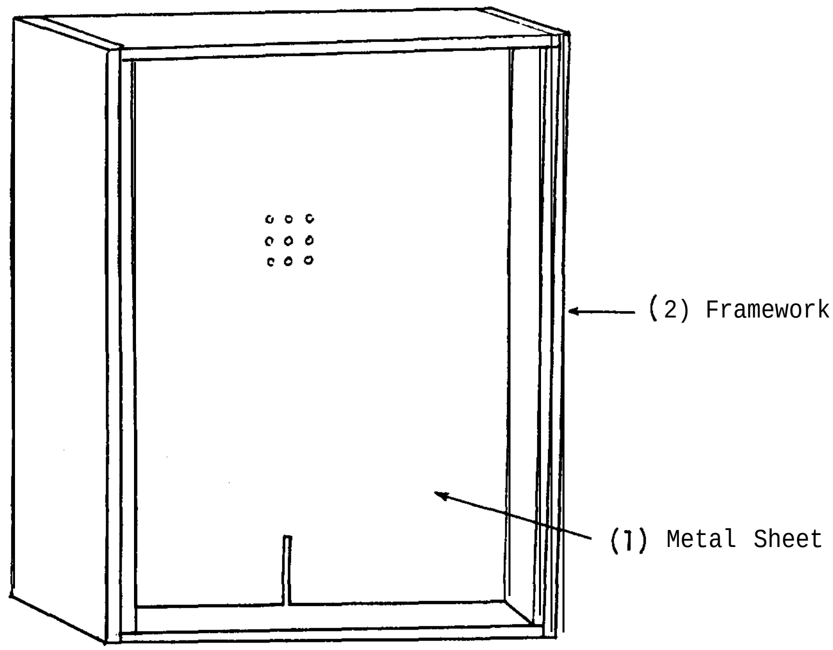


Make the base from the piece of plywood (B). Nail the two short pieces of wood (D) to the ends of the plywood (B) and nail the remaining wood strips (C) to the plywood, too. Make sure that they will hold the lamp housing firmly in position. Then nail it into position.

C. Notes

(i) This light source may be used in conjunction with the Slit/Aperture Combination (VI/AZ) to investigate the behavior of rays of light transmitted from the source. The light source is designed for use with all the items included in this chapter, including the interference and diffraction apparatus. If the bulb used is bright (e.g., 100 watts), there will be no need to black out the laboratory.

A2. Slit/Aperture Combination

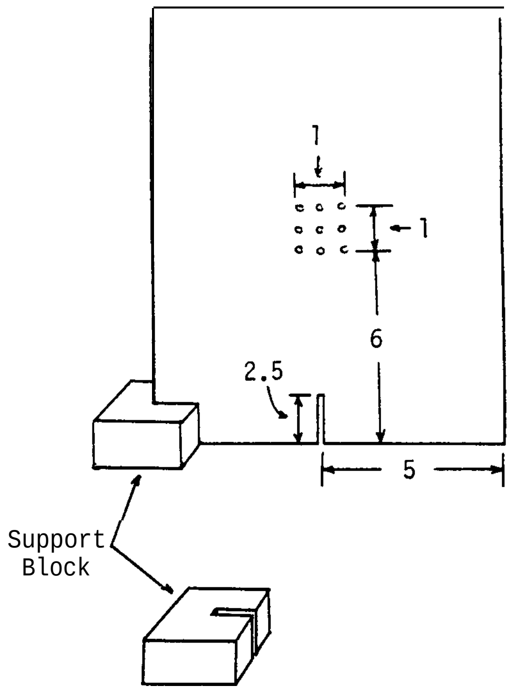


a. Materials Required

Components	Qu	Items Required	Dimensions
(1)Metal Sheet	1	Aluminum Sheet (A)	15 cm x 10 cm x 0.02 cm
(2) Framework	4	Wood Side Strips (6)	1 cm x 1 cm x 0.5 cm
	2	Wood Side Strips (C)	15 cm x 2 cm x 0.5 cm
	2	Wood Strips (D)	11 cm x 2 cm x 0.5 cm

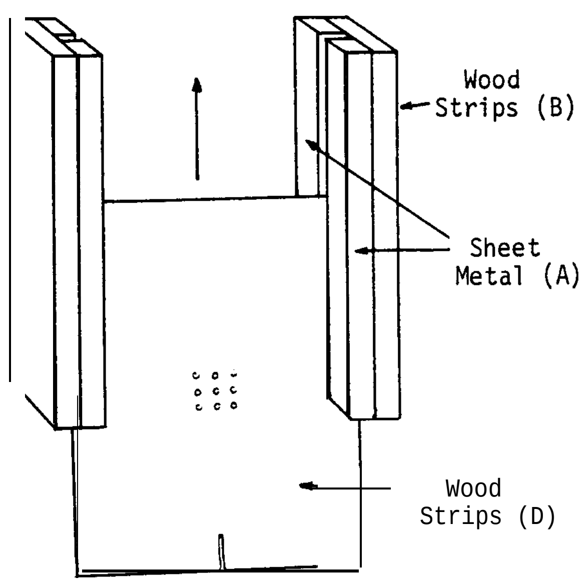
b. Construction

(1) Metal Sheet

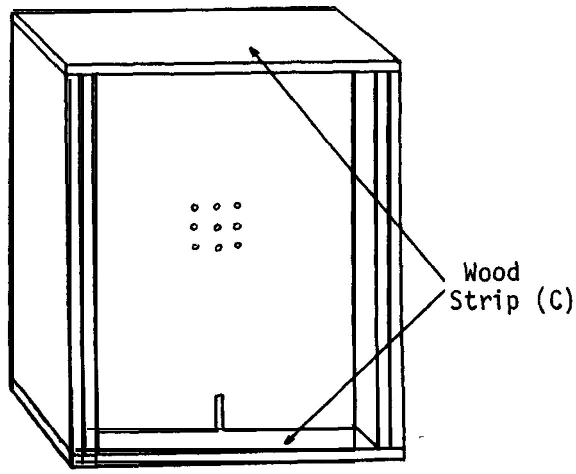


Cut the slit (0.1 cm width) and apertures (0.1 cm diameter) in any suitable thin sheeting (A) (metal, bakelite, cardboard) so long as the slit and apertures have clean cut edges. If the material used is relatively rigid, a small wooden block will provide adequate support. If the material tends to flex under its own weight, a frame-work, such as that indicated below, will be required for support.

(2) Framework



Nail or glue two wood strips (B) to a third strip (C), leaving about a 0.1 cm gap between them. Make an identical piece from the other two narrow strips (B) and the one remaining wide strip (C). Slide the metal sheet into position between the two pieces.



Nail the top and bottom pieces (D) to the two upright pieces to complete the framework. The thickness of the bottom strip (D) should not be much more than 0.5 cm, as there is a tendency for this strip to cut off a desirable portion of any light path.

c. Notes

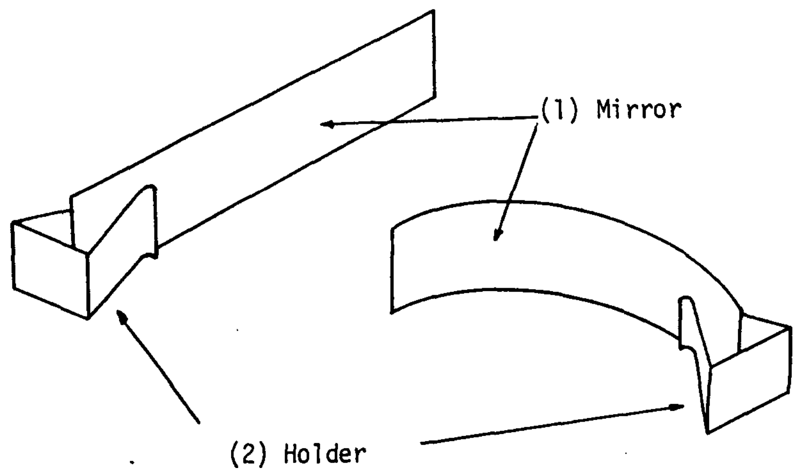
(i) The decision as to whether to use aframe will probably be one of economics. Thick metal sheets are much more expensive than thin ones, but the cost of labor involved in making a framework for a thin sheet may in some instances offset the difference between the two.

(ii) The slit is primarily intended for delineating light rays (from the Light Source, VI/A) which may be traced across a horizontal surface.

(iii) If the metal sheet is placed on itsside the apertures will sit at an appropriate height in front of the Light Source(VI/Al), and may be used as objects for experiments with lenses.

B. REFLECTION APPARATUS

Bl. Mirrors and Electroplating ©

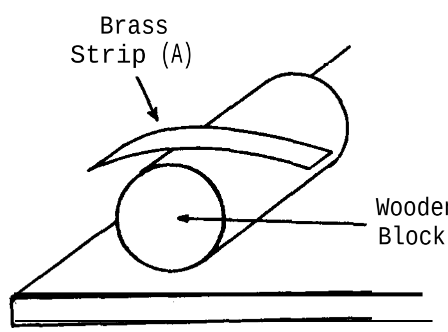


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Mirror	2	Brass Sheet (A)	10 cm x 2.5 cm x 0.1 cm
(2) Holder	2	Metal Strapping (B)	Approximately 6 cm x 2 cm x 0.02 cm
	2	Plastic Tape (C)	2 cm x l cm

b. Construction

(1) Mirror



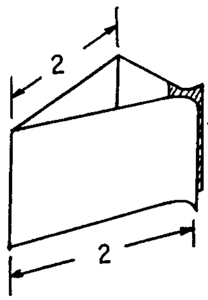
Cut the sheet of brass (A) on a metal guillotine (to be found in your nearest metalwork shop). If the metal sheet is cut with bench sheers some distortion is almost certain to result, thus lowering the quality of the mirror. If the mirror is to be curved, bend it over a smooth, curved, wooden block until the mirror becomes the arc of a circle of radius 8.5 cm.

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 101-103.

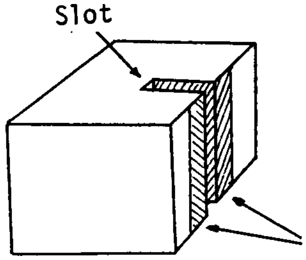
Polish the metal strips first with coarse carborundum paper, and then with successively finer and finer grades, taking care at each polishing to remove the deeper marks of the previous polishing.

Obtain a mirror finish by polishing the surface with a soft cloth and metal polish.

(2) Holder



Bend the piece of metal packing case band (B) into a triangular shape. Curve the endpieces and cover them with the plastic tape (C) to protect the mirror surface.



Alternatively, cut a slot (0.2 cm wide) in a wooden block (2 cm x 2 cm x 2 cm). Line the slot with plastic tape to prevent the wood from scratching the surface of the mirror to be held.

C. Notes

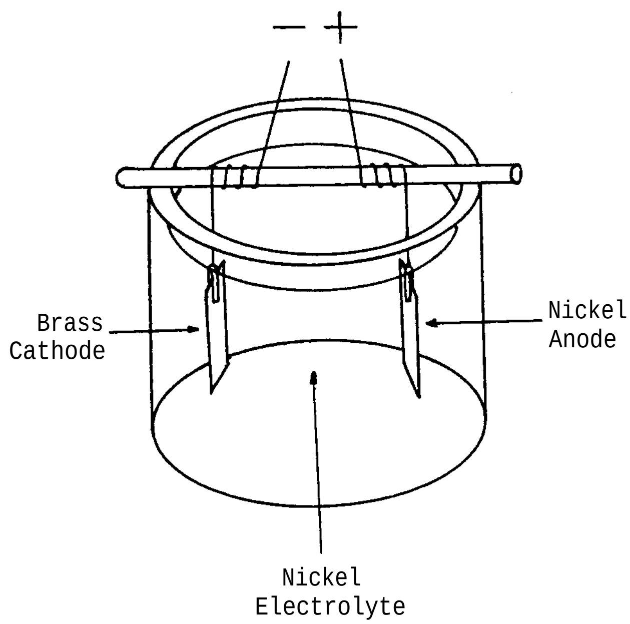
(i) Brass mirrors must be cleaned with metal polish before each usage. This process may be eliminated if the metal surface is electroplated. The procedure to be followed is described below:

Procure a plastic, or glass, container about 15 cm deep and 10 cm in diameter, and fill it with a nickel solution (e.g., Gleamax and Levelbrite).

Wash the polished brass mirror in caustic soda (soap) to remove grease and rinse with clean water. Grip the brass mirror in a crocodile clip, attached to an electrical lead, and suspend the brass mirror in the nickel solution. The mirror may be held in position by wrapping the electrical lead (by which it is suspended) around a wooden dowel bridging the container.

Suspend a nickel plate in a similar fashion from a second electrical lead. We now have an anode (nickel plate), a cathode (brass mirror) and an electrolyte (nickel solution).

Connect the anode to the positive terminal and the cathode to the negative terminal of a 6 volt battery, and pass a current through the nickel solution for 15 to 20 minutes. The quality of the final surface will depend primarily on the quality of the initial polished surface, prior to electroplating.

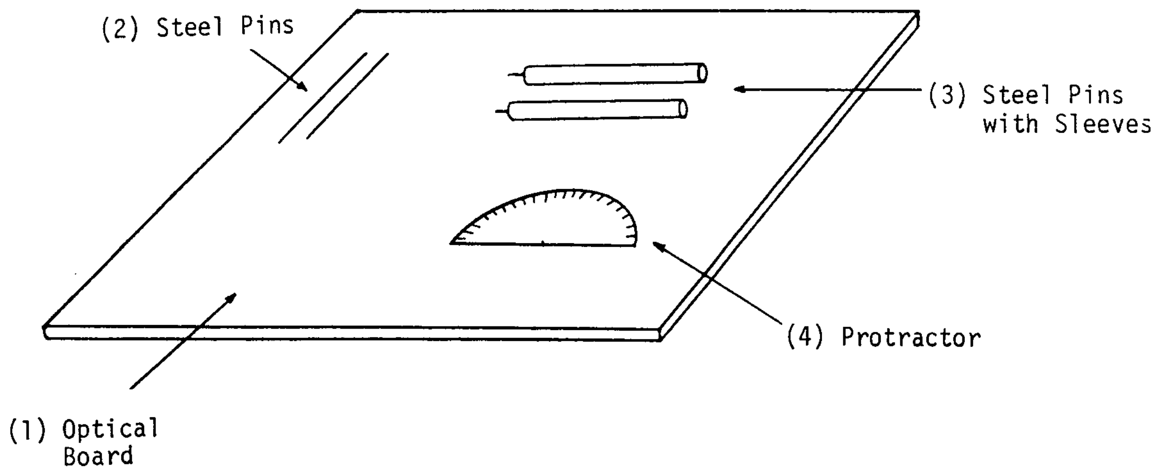


(ii) Mirrors may also be made by a very simple chemical process. Prepare three solutions as follows:

I.	II.	III.
40 ml H_2O	10 g NaOH	100 ml Concentrated fructose solution (Glucose or any aldehyde may be used, although the reaction may be slower).
60 ml Concentrated NH_4OH	100 ml H_2O	
10 g $AgNO_3$		

Just before using, mix equal volumes of solutions I and II. Then add the fructose solution to the new mixture in the ratio of 1:4. Silver will deposit on any glass surface in contact with the solution. If a microscope slide is placed in the solution, it will be coated on two sides. The external appearance will be dullish. Remove one such coating with a cloth. The glass-silver interface will be seen as an excellent mirror.

B2. Optical Board and Accessories



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Optical Board	1	Hardboard (A)	40 cm x 40 cm x 0.5 cm
(2) Steel Pins	2	Steel Rods (B)	7 cm long, 0.1 cm diameter
(3) Steel Pins with Sleeves	2	Steel Rods (C)	7 cm long, 0.1 cm diameter
	2	Pencils (D)	6.5 cm long
(4) Protractor	1	Aluminum Sheet (E)	10 cm x 5 cm x 0.05 cm

b. Construction

(1) Optical Board

This is simply a piece of hardboard (A) into which pins can be readily stuck. Normally a plain sheet of paper will be placed on top of the hardboard to facilitate the recording of experimental observations. The Refraction Model Apparatus (VI/C3) is such a piece of hardboard.

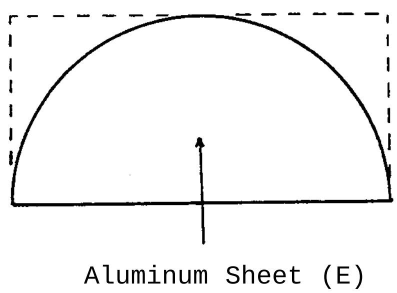
(2) Steel Pins

The steel rods (B and C) may be cut from cycle spokes or similar steel rods. Sharpen one end of each rod with the help of a file.

(3) Steel Pins with Sleeves

Remove the pencil lead from the pencils (D) with the help of a steel pin. Coat the steel pin (C) with epoxy resin, and slide it into the space originally occupied by the lead, so that, instead of the pencil lead, a steel pin protrudes from the end. Cover the sleeve with a white coat of paint.

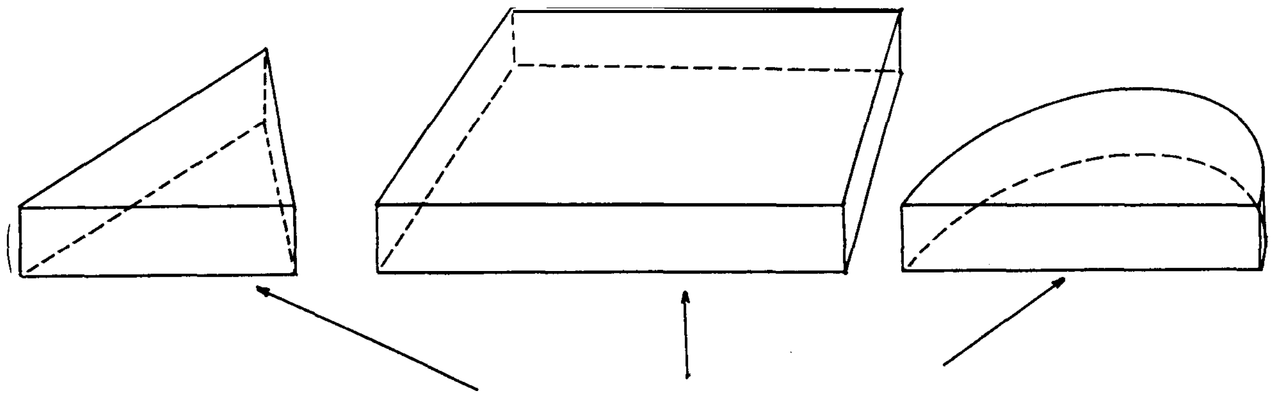
(4) Protractor



Make a protractor by cutting a semicircular piece of metal from the aluminum sheet (E). Mark as many angles around the periphery of the protractor as desired.

C. REFRACTION APPARATUS

Cl. Optical Prisms and Lenses ©



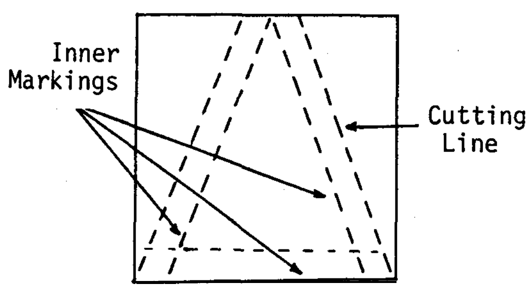
(1) Prisms

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Prisms	1	Sheet of Acrylic (A)	16 cm x 10 cm x 2 cm

b. Construction

(1) Prisms



Triangular Prism

Take the sheet of acrylic'(A) and mark out the shape of the desired prism with a sharp point. Draw a parallel set of lines about 0.5 cm outside the initial marking. The inner markings should outline a triangle (3 cm x 3 cm x 3 cm), a rectangle (8 cm x 5 cm) and a semicircle (9 cm diameter).

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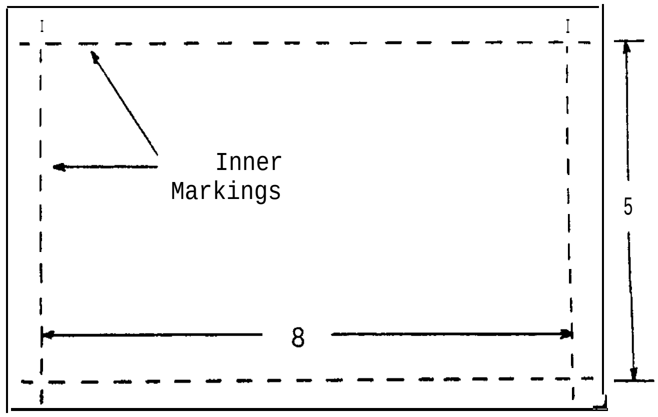
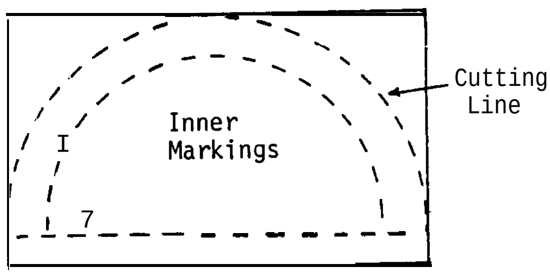
Using a fine-toothed saw, carefully cut the plastic down to the outer markings. The cut produced will have very jagged edges, the plastic showing a tendency to chip. This is normal, and should cause no concern.

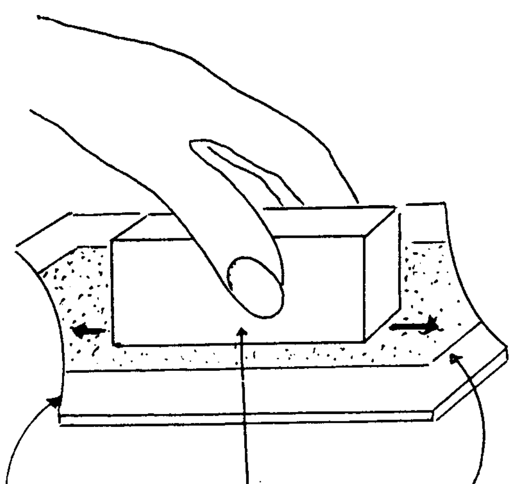


Rectangular Prism



Semicircular Prism

The next step is to remove the rough edges from the prism, reducing its size to that of the inner markings. For this purpose place a coarse sheet of Carborundum paper on top of a smooth surface (e.g., a strong glass sheet). Then smooth down the surfaces of the prism by rubbing them on the Carborundum surface.



Repeat the process with successively finer and finer grades of Carborundum paper, taking care at each rubbing to remove the deeper marks of the previous rubbing.

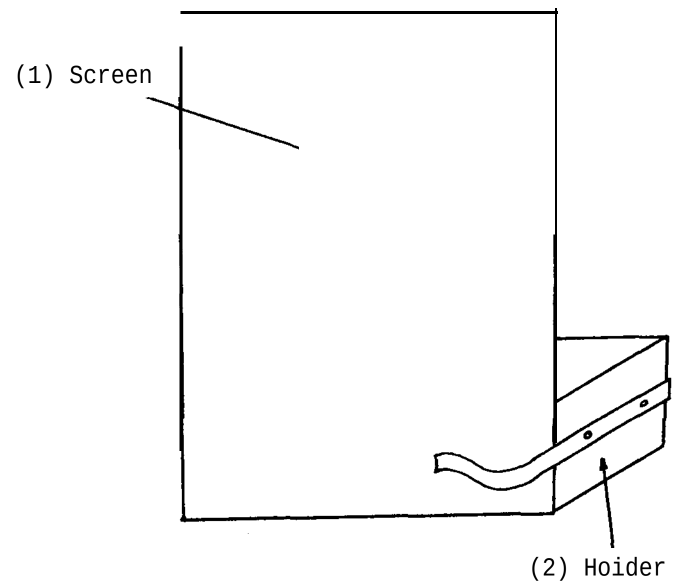
Finally, replace the Carborundum paper by a sheet of plain paper. Drop a little metal polish on the paper, and repeat the rubbing process. The surface produced will be highly polished.

The rubbing and polishing process is repeated with all the surfaces except that surface which will normally be in contact with the table top during experimentation. This surface is smoothed with Carborundum paper, but not metal polish, thus leaving the surface sufficiently rough to scatter light.

c. Notes

(i) Plastic is not as hard as glass, and is therefore more easily scratched and damaged. From time to time it is therefore necessary to repolish the surfaces with metal polish, as described above.

C2. Screen with Holder



a. Materials Required

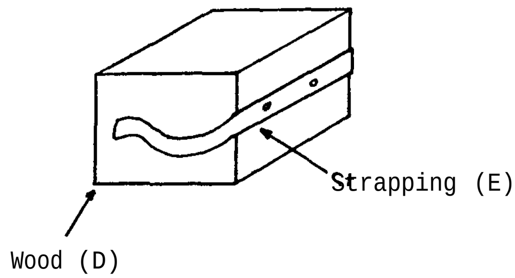
Components	Qu	Items Required	Dimensions
(1) Screen	1	Cardboard (A)	25 cm x 15 cm
	1	White Paper (B)	25 cm x 15 cm
	1	Black Paper (C)	25 cm x 15 cm
(2) Holder	1	Wood Block (D)	4 cm x 4 cm x 4 cm
	1	Steel Band (E)	Approximately 8 cm x 1 cm x 0.02 cm

b. Construction

(1) Screen

Make the screen from the stiff piece of cardboard (A). It is very convenient to have a front white surface and a rear black surface. This may be achieved by sticking appropriate sheets of paper (B,C) on the two surfaces.

(2) Holder

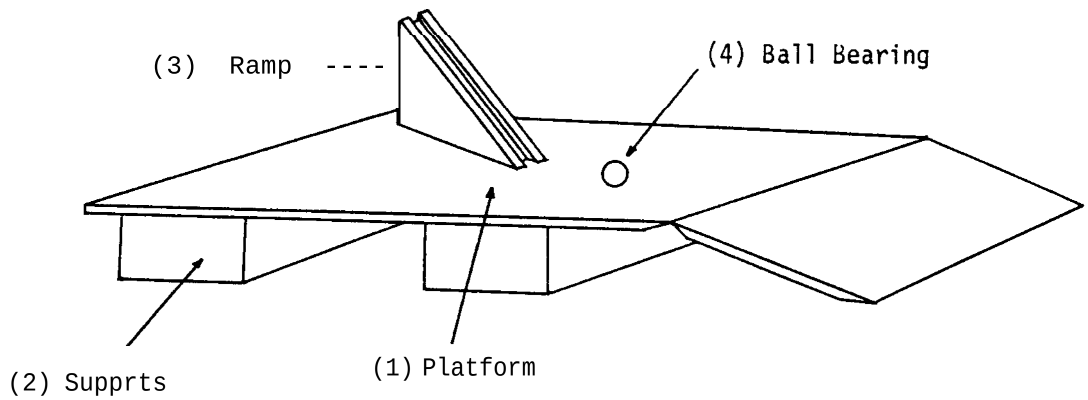


Bend a length of packing case steel (E) as shown and nail it to the side of the wooden block (D).

C. Notes

(i) The white surface of the screen is used for normal image formation, while the black surface is useful whenever the screen is used as a barrier to exclude light.

C3. Refraction Model Apparatus

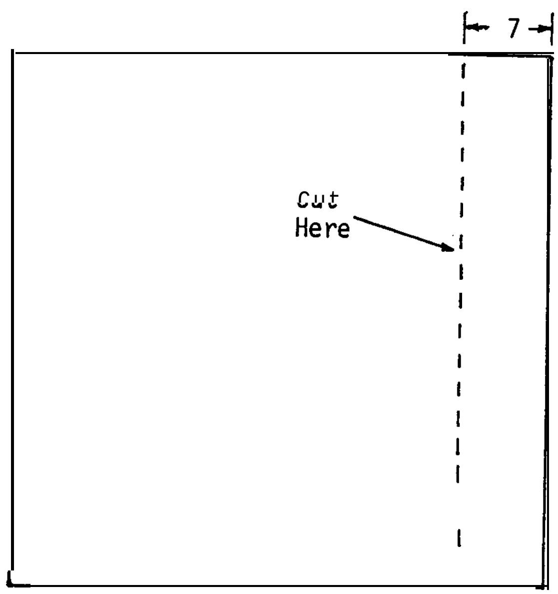


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Platform	1	Hardboard (A)	40 cm x 40 cm x 0.5 cm
	2	Hinges (B)	Approximately 2 cm long, sidepieces no more than 0.5 cm wide
(2) Supports	2	Wood (C)	30 cm x 4 cm x 2 cm
(3) Ramps	1	Wood (D)	12 cm x 5 cm x 2 cm
	1	Wood (E)	12 cm x 3 cm x 2 cm
(4) Ball Bearing	1	Ball Bearing (F)	2.5 cm diameter

b. Construction

(1) Platform

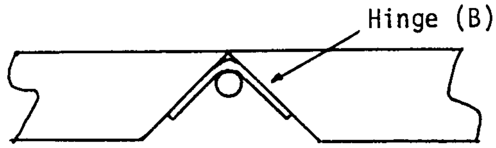


Hardboard (A)

Cut a 7 cm strip from one side of the plywood (A), and shape the newly cut edges back at an angle of 45° as illustrated. Reattach the 7 cm strip to the platform with very small hinges (B) avoiding the creation of a gap between the strip and main platform. Shape the free edge of the 7 cm strip to an angle of 45°. This shaping insures good contact between the strip and the table.

(Also see illustration on next page.)

Side View



Detail

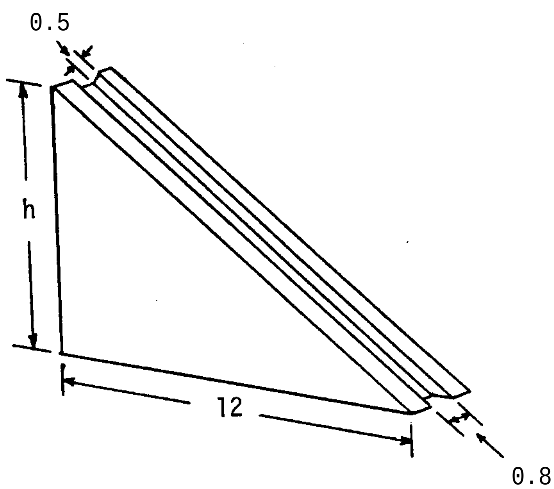
(2) Supports

Books, or blocks of wood (C), may be used to elevate the platform to different heights above the table top (e.g., 2 and 4 cm).

(3) Ramp

Cut two triangular shapes out of the pieces of wood (D,E). The height (h) of one triangular shape will be 5 cm and the other will be 3 cm, while both will have a base 12 cm long.

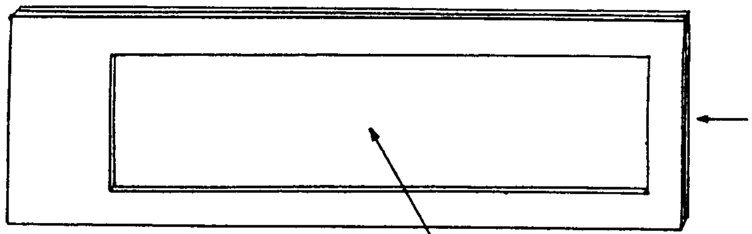
The groove is best cut with the help of a saw.



C. Notes

(i) This apparatus is used to demonstrate the refraction of light according to Newton's Corpuscular Theory. The ball bearing may be rolled down the small ramp, across the top platform and down the ramp, or alternatively down the large ramp, across the table top and up the ramp. In either case refraction occurs in crossing the ramp from one level (or medium) to another, and appropriate comparisons may be made with the transmission of light across a boundary (ramp) from one medium (level) to another.

C4. Filter

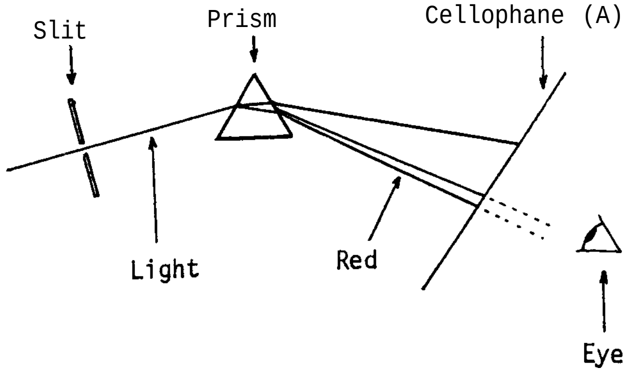


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Cellophane	1	Red Cellophane (A)	10 cm x 3 cm
(2) Frame	2	Cardboard (B)	10 cm x 3 cm

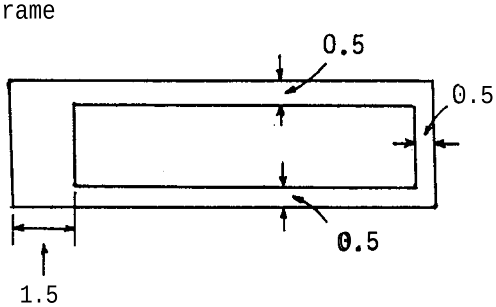
b. Construction

(1) Cellophane



Test different strips of red cellophane (A) for suitability by noting what parts of a spectrum can be seen through the cellophane. The cellophane cutting out almost all colors other than red will be most suitable.

(2) Frame



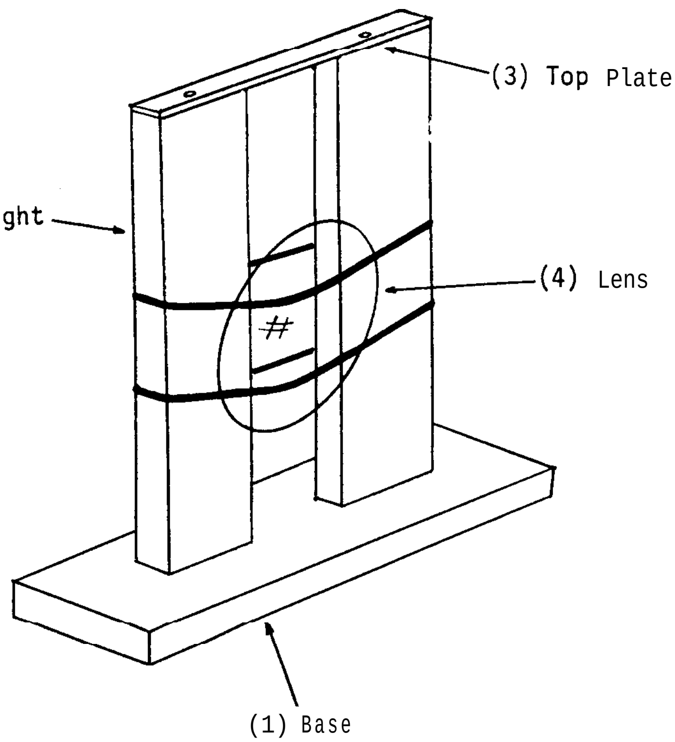
Cut the two pieces of cardboard (B) to the shape indicated, and stick (or clip) a suitable piece of red cellophane (A) between the two pieces.

C. Notes

(i) Filters are very useful not only in studying the way in which different colors of light superimpose one on the other, but also for the creation of monochromatic light. This is particularly important in studying interference and diffraction phenomena.

D. LENS APPARATUS

Dl. Lens with Holder ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	10 cmx5 cmxl cm
(2) Uprights	2	Wood Strips (B)	12cmx2cmxlcm
	2	Screws (C)	1.5 cm long
(3) Top Plate	1	Metal Sheet (D)	7 cm x 1 cm x 0.1 cm
	2	Screws (E)	Approximately 0.7 cm long
(4) Lens	1	Magnifying Glass (F)	--

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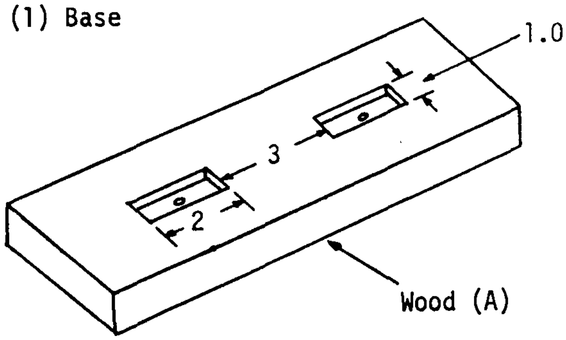
b. Construction

(1) Base



Make two insets (0.5 cm deep) in the wood (A) to take the two uprights (B). Drill a small hole (0.2 cm diameter) in the middle of each inset.

(2) Uprights

Set the uprights (B) in the base insets with wood cement, insuring a firm joint by screwing the very small screws (C) through the base into the upright.

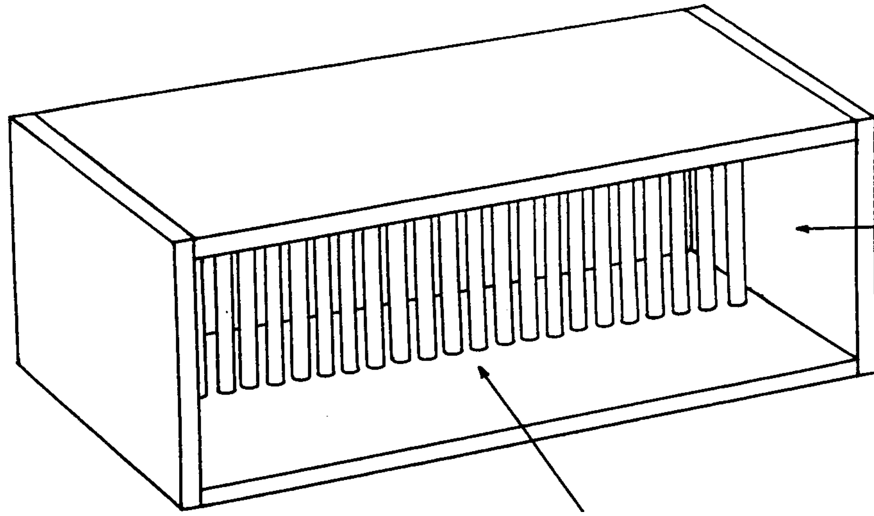
(3) Top Plate

Cut the top plate out of aluminum or brass (D). Drill a small hole (0.2 cm diameter) at a distance of 1 cm from each end. Attach the top plate to the uprights with very small screws (E).

(4) Lens

Purchase a suitable magnifying glass (F) locally. It may be held in any position on the upright by means of rubber bands.

D2. Multiple Slits

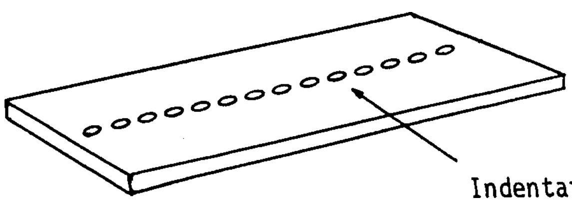


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Framework	2	Wood Strips (A)	10 cm x 2 cm x 0.5 cm
	2	Wood Strips (B)	4 cm x 2 cm x 0.5 cm
(2) Nails	1	Box of Nails (C)	0.2 cm diameter, more than 4 cm long

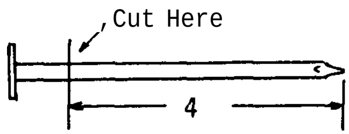
b. Construction

(1) Framework



Make regular indentations down the middle of the top and bottom strips (A) of the framework, the indentations being 0.4 cm apart. These indentations can easily be made with a hammer and nail. The remaining two pieces of wood (B) will serve as sidepieces for the framework. Do not complete construction of the framework until the nails (C) are in place.

(2) Nails



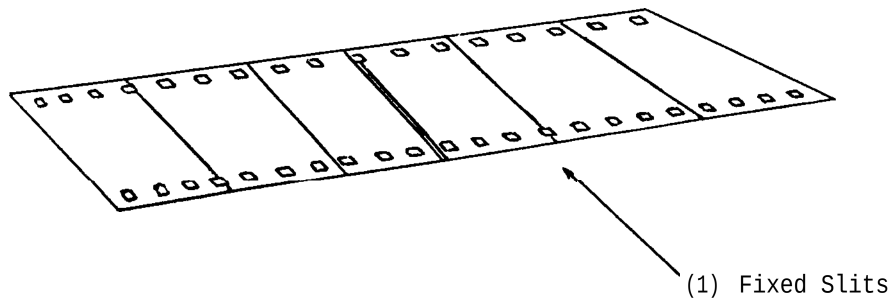
Take a handful of nails (C) and cut off the top ends to produce a uniform set of nails, each 4 cm long. Tap the nails into the bottom strip (A), positioning them in the indentations. Then press the upper strip (A) onto the upright nails, using the indentations on the upper strip for guidance in positioning the nails parallel to one another. Finally, attach the sidepieces (B) of the framework using very small nails or wood cement.

c. Notes

(i) The multiple slits are used primarily to break up beams of light into multiple pencils of light. Many alternative devices could be used for the same purpose, e.g., a hair comb supported by a wooden block.

E. DIFFRACTION AND INTERFERENCE APPARATUS

El. Fixed Single and Double Slits

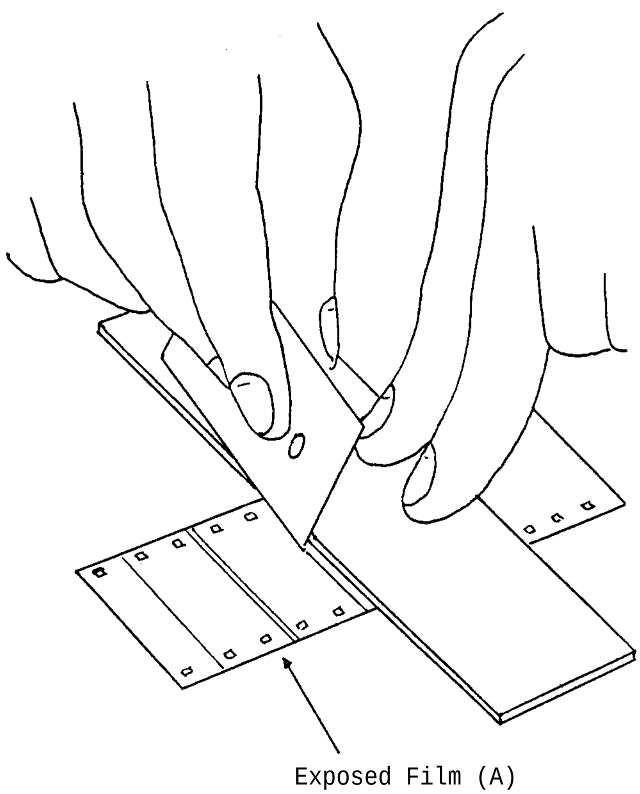


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Fixed Slits	1	Exposed Film (A)	Approximately 5 cm x 3.5 cm

b. Construction

(1) Fixed Slits



Take an exposed strip of film (A) (or a slide coated with colloidal graphite) and draw a straight line across it using a razor and a straight edge as a marker. The width of the slit may be increased, if desired, by drawing the razor over the same approximate line two or three times. Do not cut through the film.

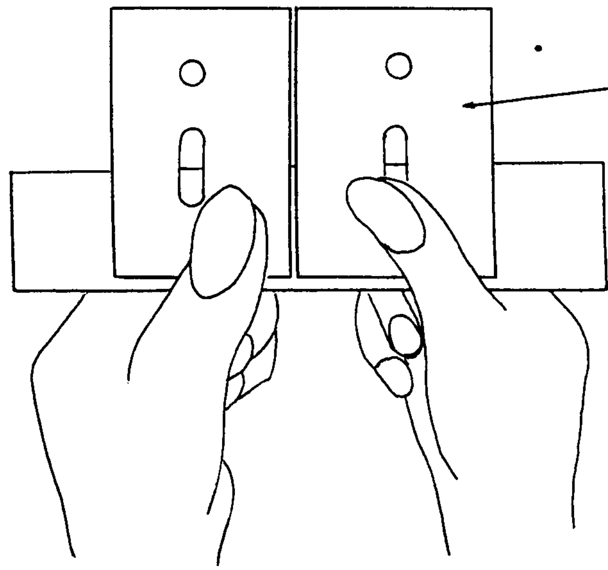
A double slit may be made in an almost identical way, Simply hold two razors face to face, and draw the line across the film with the two razor blades pressed closely together. The space between the slits may be increased, if desired, by holding the blades at an angle to the vertical as the double line is drawn against the straight edge.

C. Notes

(i) In making single or double slits it is well worthwhile repeating the procedure several times on different parts of the film, and then selecting the best slits after testing.

(ii) If the slits are held in a vertical position close to the eye, and if the vertical filament of the Light Source (VI/Al) at a distance of about three meters is viewed through the slits, interference and diffraction patterns will be observed even in daylight. The patterns are clarified by the use of the Filter (VI/C4) placed in front of the slits.

E2. Adjustable Single Slit



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) **Adjustable Slit**	2	Razor Blades (A)	--
	1	Metal Strip (B)	Approximately 7 cm x 2 cm

b. Construction

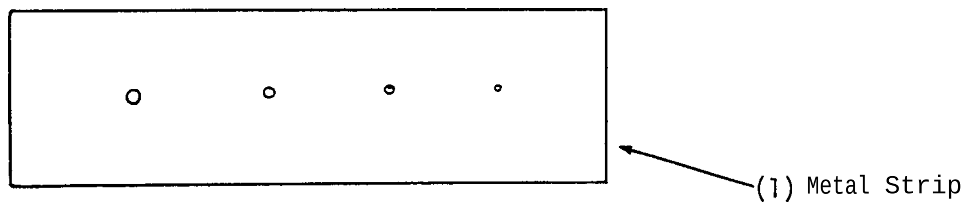
(1) Adjustable Slit

Hold the two razor blades (A) against the metal strip (B) so that the edges of the blades are almost touching and are parallel to one another.

c. Notes

(i) If the slit is held in a vertical position close to the eye, and the vertical filament of the Light Source (VI/Al) viewed at a distance of about three meters, a diffraction pattern may be observed in daylight conditions. The pattern is clarified by the use of the Filter (VI/C4) placed in front of the slit. The effect on the pattern of changing the slit width may readily be observed.

E3. Diffraction Holes



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Metal Strip	1	Metal Strip (A)	10 cm x 2.5 cm x 0.1 cm

b. Construction

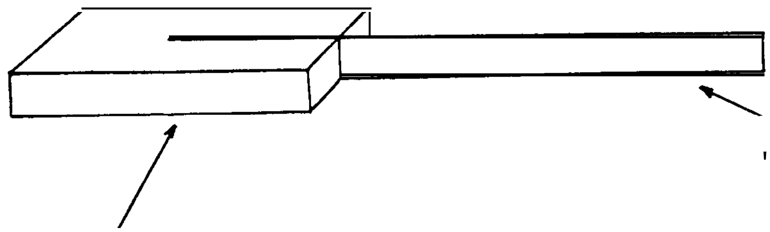
(1) Metal Strip

Drill four holes (diameters approximately 0.1, 0.08, 0.05, and 0.02 cm) in the metal strip (A) at regular intervals.

c. Notes

(i) Circular diffraction patterns may be studied with these holes and the Light Source (VI/Al) placed in such a position that the light filament is viewed through the small hole in the lid of the lamp housing, thus acting as a point source. If this point source is viewed at a distance of about three meters by looking through one of the diffraction holes, when the strip is held close to the eye, a diffraction pattern will be seen even in daylight conditions. The pattern will appear clearer if the Filter (VI/C4) is placed in front of the diffraction hole.

E4. Interference Strips



a. Materials Required

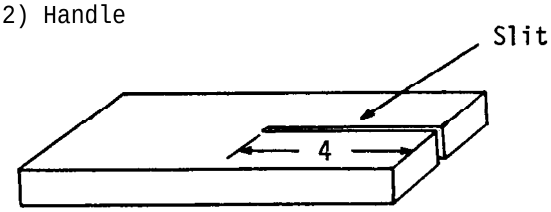
Components	Qu	Items Required	Dimensions
(1) Metal Strip	1	Metal Strip (Copper or Steel)	14 cm x 1 cm x 0.1 cm
(2) Handle	1	Wood	7 cm x 1 cm x 1 cm

b. Construction

(1) Metal Strip

The metal strip (A) may be of any desired metal. In this instance, two are specifically recommended, namely copper and steel (from packing case bands).

(2) Handle



The handle is made from the wood (B). Cut a slit down the middle of the handle with a saw. Cement the metal strip into this inset with epoxy resin.

c. Notes

(i) If the end of the metal strip is placed in 'a hot flame, interference bands will be produced on the strip.

VII. LABORATORY ACCESSORIES

Where a science room has an electric outlet teachers will wish to take advantage of the mains' supply. The apparatus described here considerably extends the usefulness of the electric outlet.

A. TRANSFORMERS

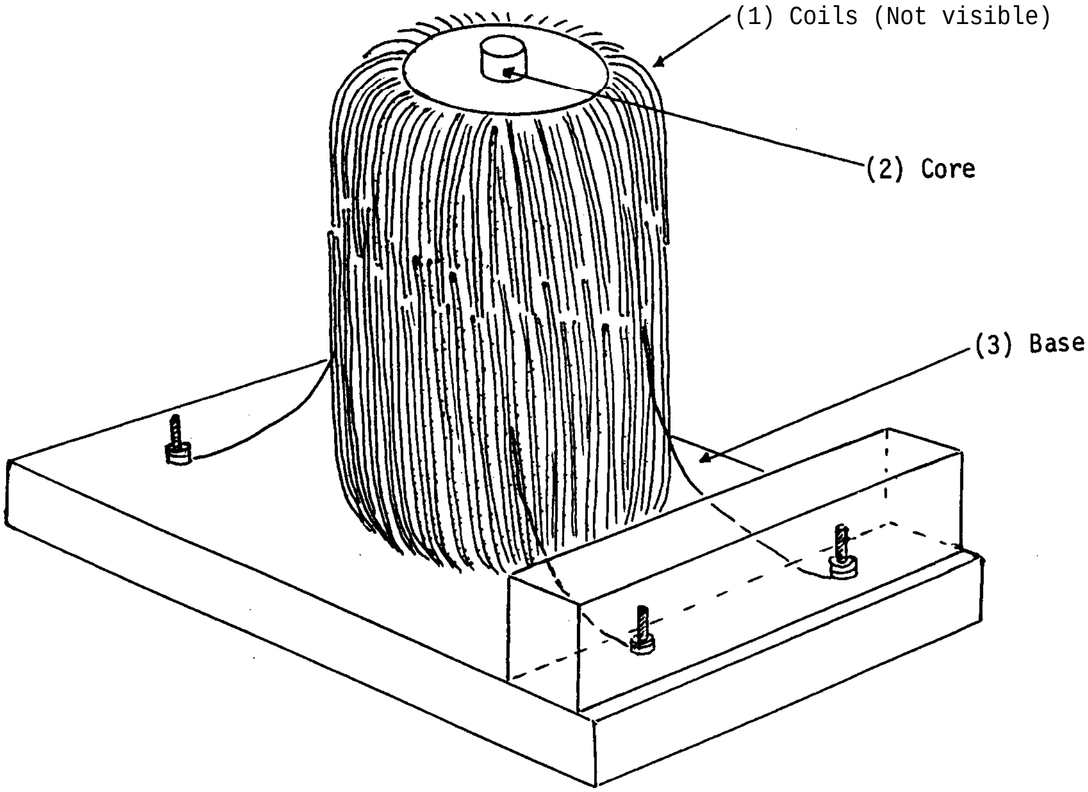
This section describes different types of transformers which may be used to produce low voltage AC outputs. The limitations of each transformer are carefully described in the notes.

B. RECTIFIERS

This section describes rectifiers, which may be used with the foregoing transformers, to produce low voltage DC current.

A. TRANSFORMERS

Al. Transformer, Iron Wire Core (6 volt output, 120 volt mains)



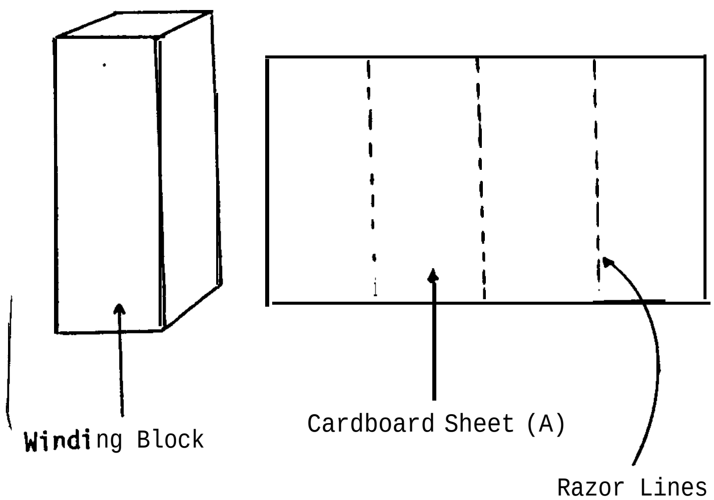
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Coils	1	Sheet of Cardboard (A)	12 cm x 7.5 cm
	1	Roll of Magnet Wire (B)	#24, 250 g
	1	Roll of Magnet Wire (C)	#20, 60 g
	1	Roll of Masking Tape (D)	--
(2) core	1	Galvanized Wire (E)	#12, 30 meters
	--	Varnish (F)	--
	1	Bolt (G)	0.5 cm diameter, 14 cm long
	1	Nut (H)	0.5 cm internal diameter
	2	Washers (I)	4 cm external diameter
(3) Base	1	Wood (J)	20 cm x 15 cm x 1.5 cm
	1	Wood (K)	15 cm x 3 cm x 2 cm

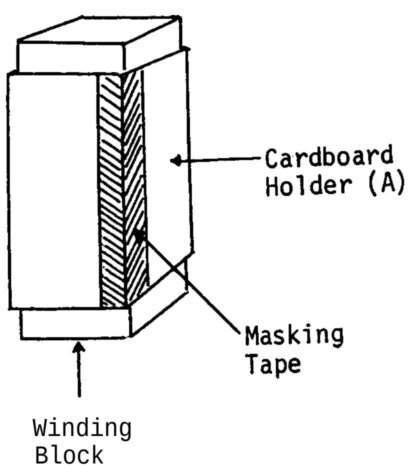
4	Bolts (L)	2.5 cm long, 0.3 cm diameter
8	Nuts (M)	0.3 cm internal diameter
--	Insulation Tape (N)	--

b. Construction

(1) Coils

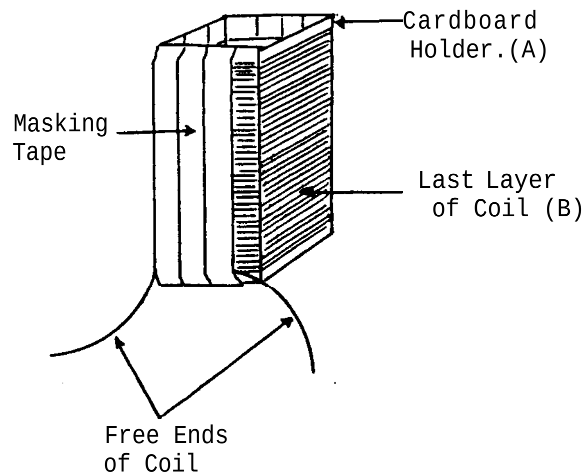


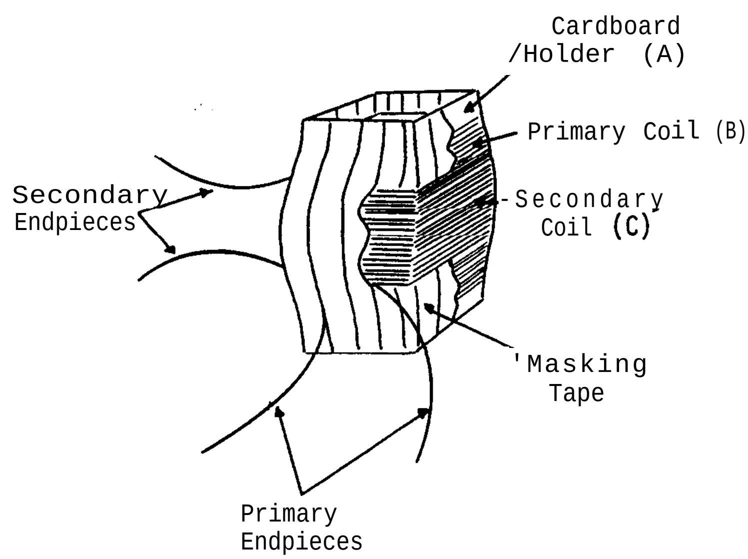
Cut a piece of wood (10 cm x 3 cm x 3 cm) to serve as a winding block for the primary and secondary coils. Take the sheet of cardboard (A) and use a razor blade to score parallel lines on it at 3 cm intervals so that it may readily be bent to the shape of the wooden block.



Wrap the cardboard around the block, fastening the two loose edges together with masking tape (D), thus producing a cardboard holder on which to wind the coils.

Wind 800 turns of #24 magnet wire (B), approximately 250 g, on to the cardboard holder to make the primary coil, leaving about 10 cm of wire free at



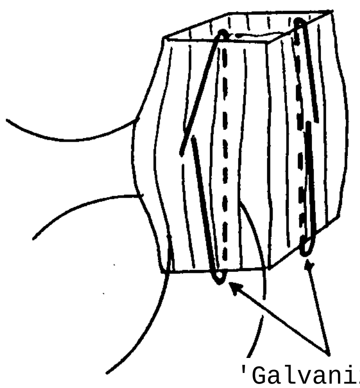


both ends. To do this a system of winding such as that described under IX/A2 should be adopted. (A variation is described in th notes below.) Wind the turns on to only the middle 6 cm or so of the cardboard holder. After winding each additional layer of turns, temporarily remove the cardboard holder (and turns) from the winding block, and cover the turns with masking tape. This not only holds the new layer of turns in position, but also insulates it from the next layer to be added.

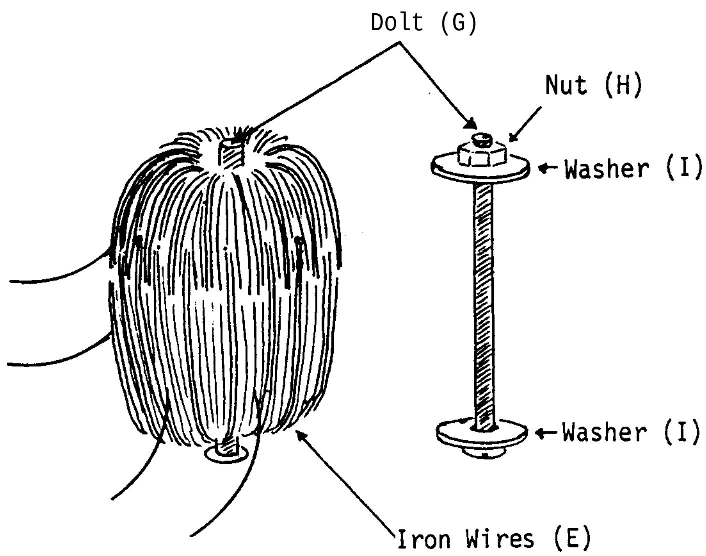
Next, take wire (C), and wind 40 turns, approximately 60 g, on top of the primary coil following the same procedures described for the primary coil, but in this case making each layer only about 3.5 cm long, instead of 6 cm. As before, insure that each layer of turns is insulated from the next with masking tape, and that some 10 cm of wire is left free at both ends of the coil. The newly added coil is appropriately labeled the secondary coil.

(2) Core

Cut the galvanized iron wire (E) into a series of 20 cm lengths. Dip these in varnish (F), and then lean them against a vertical surface to dry, in such a way that varnish is not removed from the wire in the process of drying. One to two days will be required for the varnish to dry.

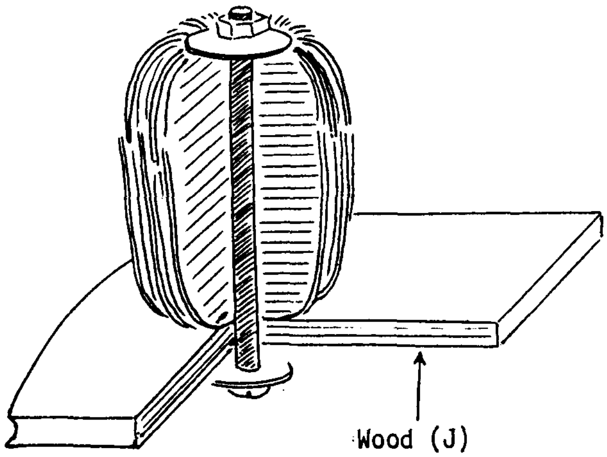


Take the dry wires one at a time, and bend them through, and around, the coil so that the wire ends just touch, or overlap, one another. If the wire is too long, cut the ends. Continue adding the iron wires to the coil in the same way, distributing the wires equally on each face of the coil, until the coil is almost full of iron wire. However, leave enough space to squeeze bolt (G) through the middle of the wire core.

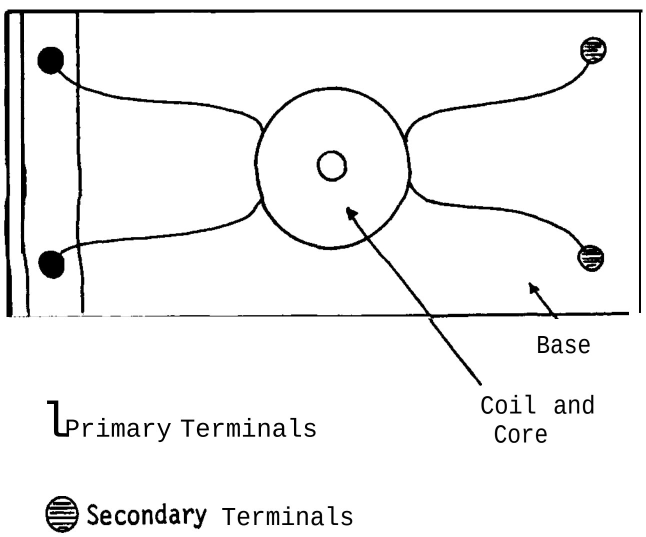


Slide bolt (G) through the middle of the iron wires. Washers (I) should be fitted on either end of the bolt, and the whole kept in position with a suitable nut (H).

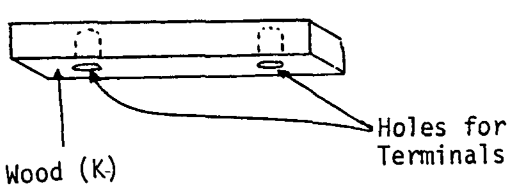
(3) Base



Make the base from wood (J). Drill a hole (diameter 0.5 cm) through the center, and attach the coil and core to the base with the help of the bolt (G) through the middle of the core. Make an inset in the bottom of the base to accommodate the bolt-head.

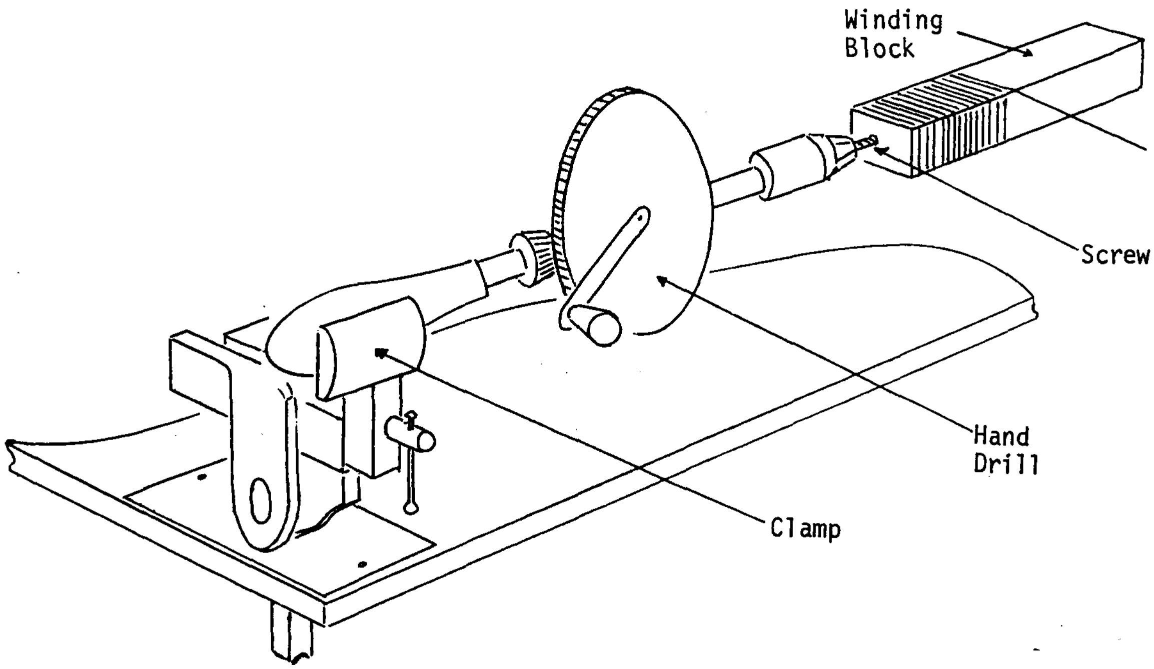


Use the bolts (L) and nuts (M) to make four terminals (as described under VIII/A2). Fit two at one end of the base to serve as secondary terminals, and attach the ends of the secondary coil to these, after cleaning the ends of the wire with sandpaper. Fit the other two terminals at the other end of the base to serve as the primary terminals. Attach the ends of the primary coil to the terminals after cleaning the ends of the wire with sandpaper. Remembering that the primary coil will be connected to the mains (120 volts) it is important to insure good insulation of all primary terminals and wires. Therefore, cover each of the wires from the primary coil to the relevant terminal with electrical insulation tape (N). In addition make a safety cover from wood (K). Simply cut holes (2 cm deep,



1 cm diameter) in the under-surface of the wood to accommodate the terminals, and set the wood on the base so that it covers the terminals.

C. Notes



(i) A convenient way of winding the coils is to use a hand drill and winding block. Clamp the tiand drill horizontally above the bench surface, and hold winding block horizontally in the drill chuck with the help of a screw fixed firmly in the end of the winding block. If a cardboard sleeve is fitted over the winding block, the wire may be wound on the sleeve, and the latter subsequently removed complete with newly wound coil.

(ii) The transformer made and tested here actually had 800 turns on the primary and 43 turns on the secondary. The voltage output was noted to be 6.6 volts when the current load was at a minimum, and that it fell to 5.5 volts as the load increased to 4 amps. At the same time the efficiency of the transformer increased from 32% at 6.6 volts to 45% at 5.5 volts.

(iii) Tested under a continuous load of 4 amps, the temperature of the core rose to 69°C over a period of 50 minutes, at which point the load was cut off to prevent serious overheating of the core. The data, indicated below, suggested that this transformer could be used continuously under a load of 3 amps, but with a load of 4 amps it should not be used for periods exceeding 30 minutes at any given time.

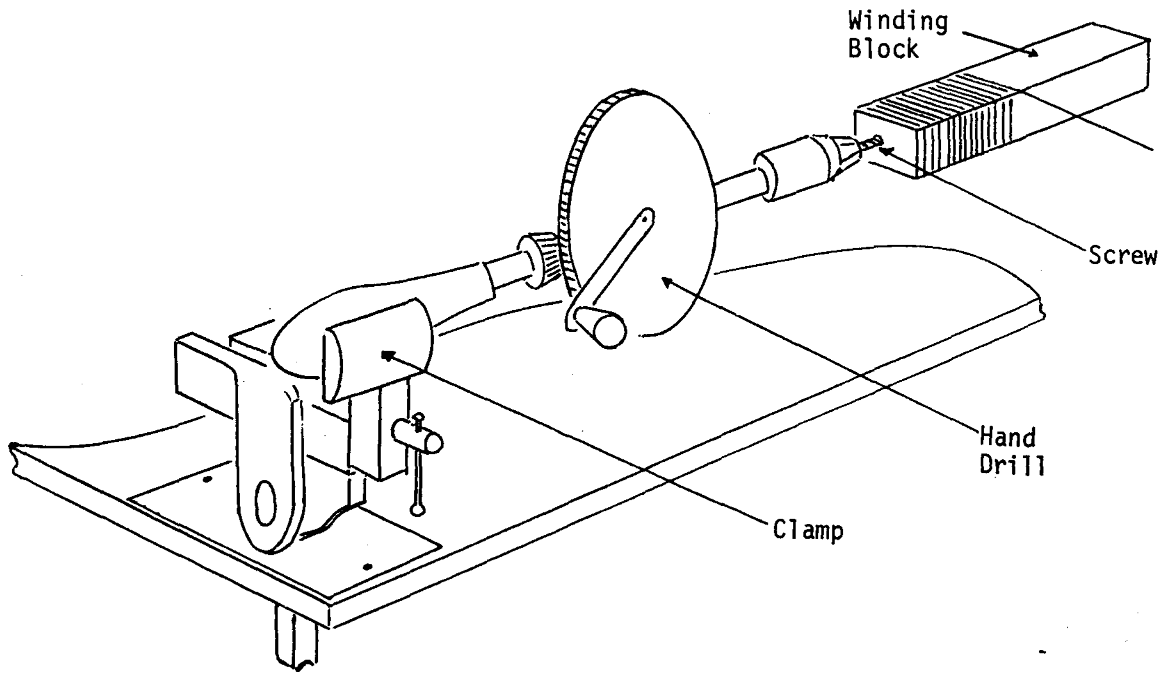
Room Temperature	output Voltage	output Amperage	Running Time	Core Temperature
ºC	Volts	Amps	Minutes	ºC
24	5.5	4	0	24
			20	50
			40	64
			50	68
			Testing stopped after 50 min	

Under the smaller load of 2.8 amps the core heated up more slowly, stabilizing at 62ºC.

Room Temperature	output Voltage	output Amperage	Running Time	Core Temperature
ºC	Volts	Amps	Minutes	ºC
24	6.0	2.8	0	24
			20	46
			40	56
			60	62

1 cm diameter) in the under-surface of the wood to accommodate the terminals, and set the wood on the base so that it covers the terminals.

c.Notes



(i) A convenient way of winding the coils is to use a hand drill and winding block. Clamp the tiand drill horizontally above the bench surface, and hold a winding block horizontally in the drill chuck with the help of a screw fixed firmly in the end of the winding block. If a cardboard sleeve is fitted over the winding block, the wire may be wound on the sleeve, and the latter subsequently removed complete with newly wound coil.

(ii) The transformer made and tested here actually had 800 turns on the primary and 43 turns on the secondary. The voltage output was noted to be 6.6 volts when the current load was at a minimum, and that it fell to 5.5 volts as the load increased to 4 amps. At the same time the efficiency of the transformer increased from 32% at 6.6 volts to 45% at 5.5 volts.

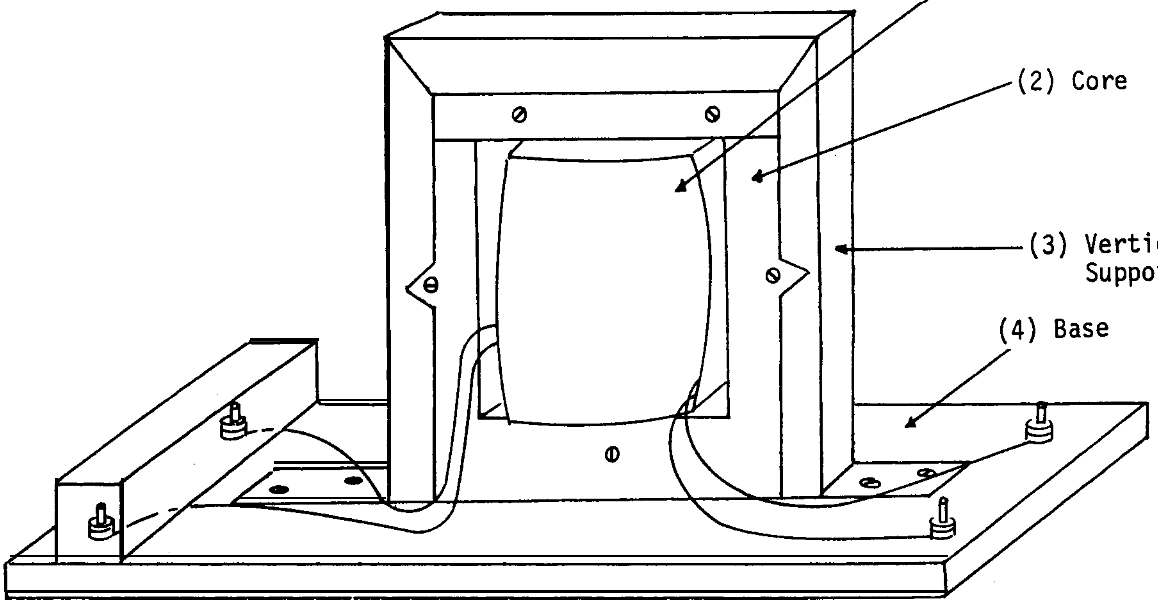
(iii) Tested under a continuous load of 4 amps, the temperature of the core rose to 69°C over a period of 50 minutes, at which point the load was cut off to prevent serious overheating of the core. The data, indicated below, suggested that this transformer could be used continuously under a load of 3 amps, but with a load of 4 amps it should not be used for periods exceeding 30 minutes at any given time.

Room Temperature	output Voltage	output Amperage	Running Time	Core Temperature
°C	Volts	Amps	Minutes	°C
24	5.5	4	0	24
			20	50
			40	64
			50	68
			Testing stopped after 50 min	

Under the smaller load of 2.8 amps the core heated up more slowly, stabilizing at 62°C.

Room Temperature	output Voltage	output Amperage	Running Time	Core Temperature
°C	Volts	Amps	Minutes	°C
24	6.0	2.8	0	24
			20	46
			40	56
			60	62

A2. Transformer, Sheet Iron Core (12 volt output, 120 volt mains)



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Coils	1	Sheet of Cardboard (A)	12 cm x 7.5 cm
	1	Roll of Magnet Wire (B)	#24, 250 g
	1	Roll of Magnet Wire (C)	#20, 100 g
	1	Roll of Masking Tape (D)	--
(2) Core	60	Galvanized Iron Sheets (E) (more sheets required if thinner sheeting is used)	13 cm x 10 cm x 0.05 an
	5	Bolts (F)	0.3 cm diameter, 3.5 cm long
	5	Nuts (G)	0.3 cm internal diameter
	--	Varnish (H)	--
(3) Vertical Support	1	Galvanized Iron or Aluminum Sheet (I)	47.5 x 5 x 0.02 all
(4) Base	1	Wood (J)	30 cm x 15 cm x 1.5 cm
	1	Wood (K)	15 cm x 3 cm x 2 cm
	4	Bolts (L)	2.5 cm long, 0.3 cm diameter
	8	Nuts (M)	0.3 cm internal diameter

-- Insulation Tape (N) --

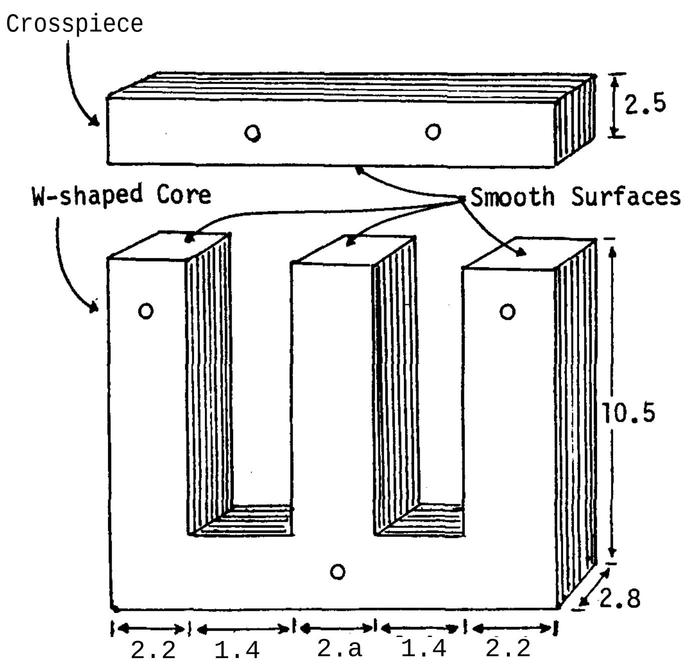
b. Construction

(1) Coils

Follow the instructions given with the foregoing transformer (VII/Al) for the construction of the coils. Make a form, on which to wind the coils, from the cardboard sheet (A), and wind BOO turns of magnet wire (B) on to the form to make the primary coil. Then wind BO turns (not 40) of magnet wire (C) on to the coil to make the secondary coil.

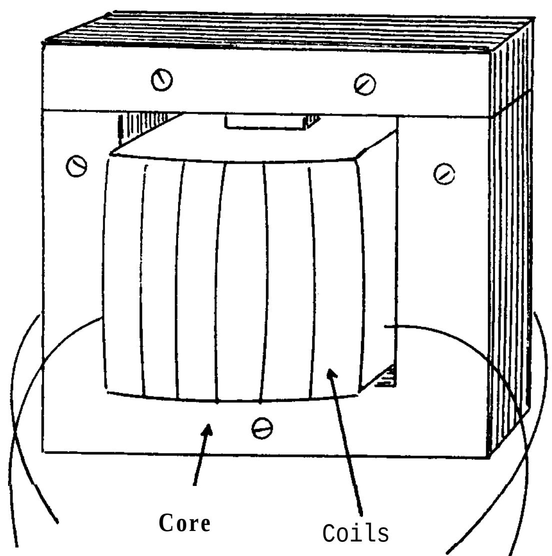
(2) Core

Stack the sheets of galvanized iron (E) one on top of the other, until they make a pile 2.B cm thick. This will require 55, or more, sheets, dependent on the thickness of each. Then cut each sheet as illustrated to form a W-shaped core piece and a rectangular crosspiece.



o Bolt Holes

Stack the newly cut plates back on top of each other, and drill five bolt holes (diameter 0.4 cm) through the plates. A drill press is preferred for this purpose, but it is possible to hand drill each plate separately. Use nuts (G) and bolts (F) to



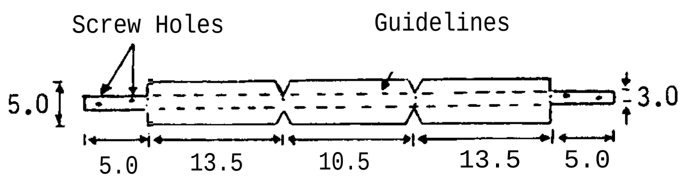
fasten the plates of the cross-piece and core together.

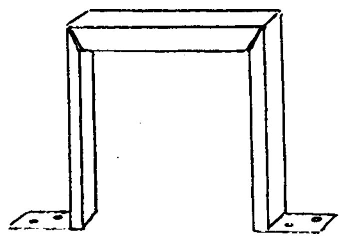
Take a file to smooth off the rough edges of the newly made core. It is important that the finished surfaces should insure good contact between the top of the W-shaped core and the crosspiece.

Now take the plates apart, paint varnish (H) on each in turn, reassembling the plates while still wet. The varnish acts as. an insulator, which reduces eddy currents, and hence heating effects, within the core. The core may take one or two days to dry.

Assemble the coils on the W-shaped core, using paper or wood wedges if necessary to insure the coil is held firmly on the central upright of the core.

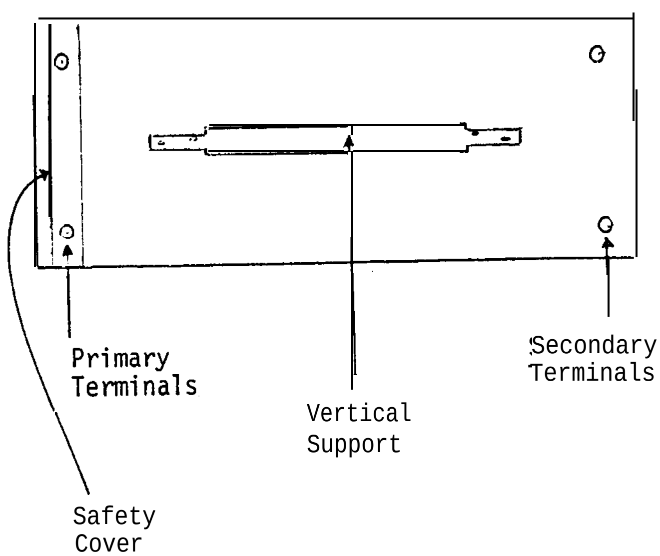
(3) Vertical Support





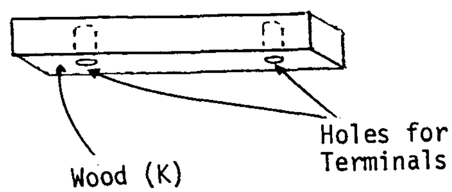
Use galvanized iron or aluminum sheeting (I) to make the vertical support. Cut it to the dimensions indicated, and bend it into the shape of a bridge. Drill two holes (diameter 0.3 cm) in either foot of the bridge so that the support may subsequently be attached to a base with screws.

(4) Base



Make a base for the transformer out of wood.(J). Fit the vertical support snugly over the core and coils, and attach the support to the middle of the base with screws.

Use bolts (L) and nuts (M) to make four terminals [as described under VIII/A2, Component (4)]. Fit two at one end of the base to serve as secondary terminals, and attach the ends of the secondary coil to these after cleaning the ends of the wire with sandpaper. Fit the other two terminals at the other end of the base to serve as the primary terminals. Attach the ends of the primary coil to the terminals after cleaning the ends of the wire with sandpaper. Remembering that the primary coil will be connected to the mains (120 volts),it is important to insure good insulation of all



primary terminals and wires. Therefore, cover each of the wires from the primary coil to the relevant terminal with electrical insulation tape (N).

In addition, make a safety cover for the primary terminals from wood (K). Simply cut holes (2 cm deep, 1 cm diameter) in the undersurface to accommodate the terminals, and set the wood on the base so that it covers the terminals.

c. Notes

(i) The voltage output of the secondary coil of the transformer will be at a maximum when the current load is at a minimum. In this case it was noted that the output voltage fell from 12 volts at 1 amp to 11 volts at 4 amps. At the same time the efficiency of the transformer increased from 47% at 12 volts to 62% at 11 volts.

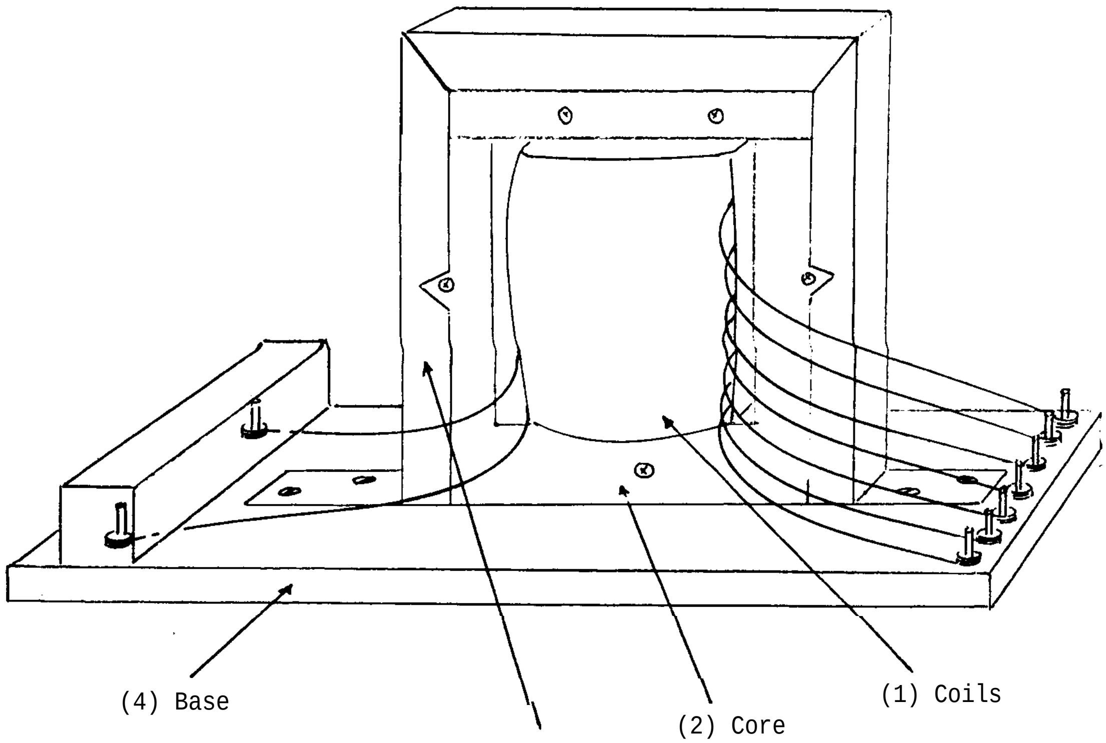
(ii) Tested over a period of 90 minutes under a continuous load of 4 amps, the temperature of the core remained well within acceptable limits. The following data indicates the degree of heating somewhat more explicitly.

Room Temperature	output Voltage	output Amperage	Running Time	core Temperature
°C	Volts	Amps	Minutes	°C
24	10.8	4	0	24
			20	52
			40	56
			60	59
			90	59

Under smaller loads the core heats up more slowly, but observations tended to suggest that the ultimate equilibrium temperature achieved (59°C) was the same as with the heavier load. (See table on next page.)

Room Temperature	output Voltage	output Amperage	Running Time	Core Temperature
°C	Volts	Amps	Minutes	°C
24	11	3	0	24
			20	44
			40	52
			60	59

A3. Transformer, Variable Output (120 volt mains)



a. Materials Required

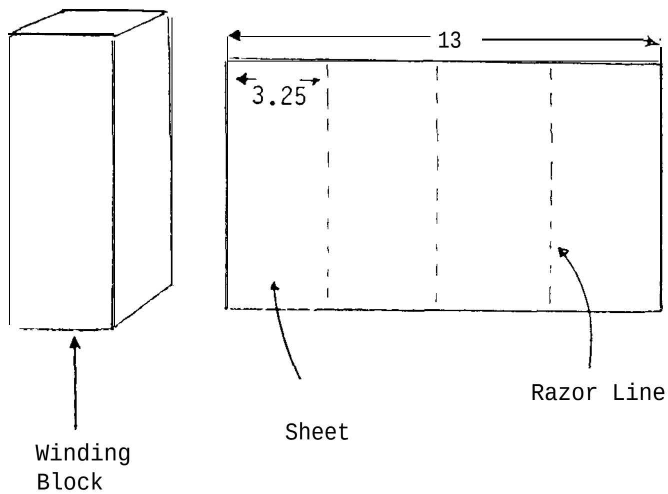
Components	Qu	Items Required	Dimensions
(1) Coils	1	Cardboard Sheet (A)	13.0 cm x 11.5 cm
	1	Roll of Magnet Wire (B)	#24, 250 g
	1	Roll of Magnet Wire (C)	#20, 250 g
	1	Masking Tape (D)	--
(2) Core	60	Galvanized Iron Sheets (E) (more sheets required if thinner sheeting is used)	17 cm x 10 cm x 0.05 cm
	5	Bolts (F)	0.3 cm diameter, 3.5 cm long
	5	Nuts (G)	0.3 cm internal diameter
	1	Can of Varnish (H)	--
(3) Vertical Support	1	Galvanized Iron or Aluminum Sheet	55.5 cm x 5 cm x 0.02 cm
(4) Base	1	Wood (J)	30 cm x 20 cm x 1.5 cm
	1	Wood (K)	20 cm x 3 cm x 2 cm

9	Bolts (L)	2.5 cm long, 0.3 cm diameter
18	Nuts (M)	0.3 cm internal diameter
1	Roll of Insulation Tape (N)	--

b. Construction

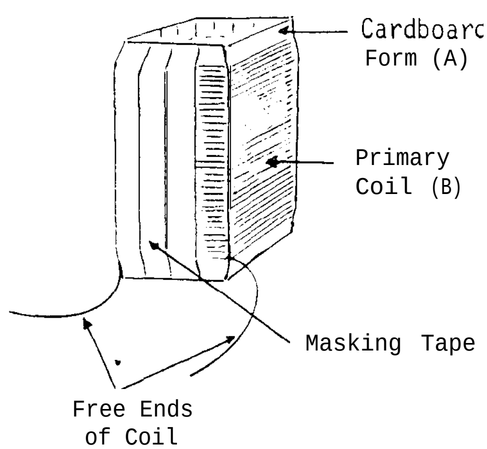
(1) Coils

Cut a piece of wood (14 cm x 3.2 cm x 3.2 cm) to serve as a winding block for the primary and secondary coils. Take the thin sheet of cardboard (A) and use a razor blade to score parallel lines on it at intervals of 3.25 cm, so that the cardboard may readily be bent around the wooden block.

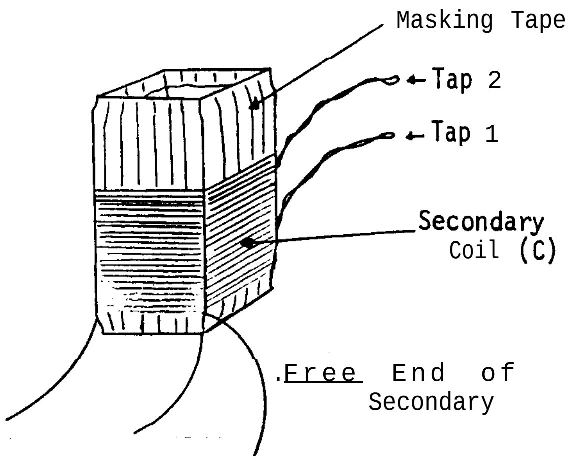


Wrap the cardboard sheet around the block, fastening the loose edges together with masking tape (D), thus producing a cardboard form on which to wind the primary and secondary coils.

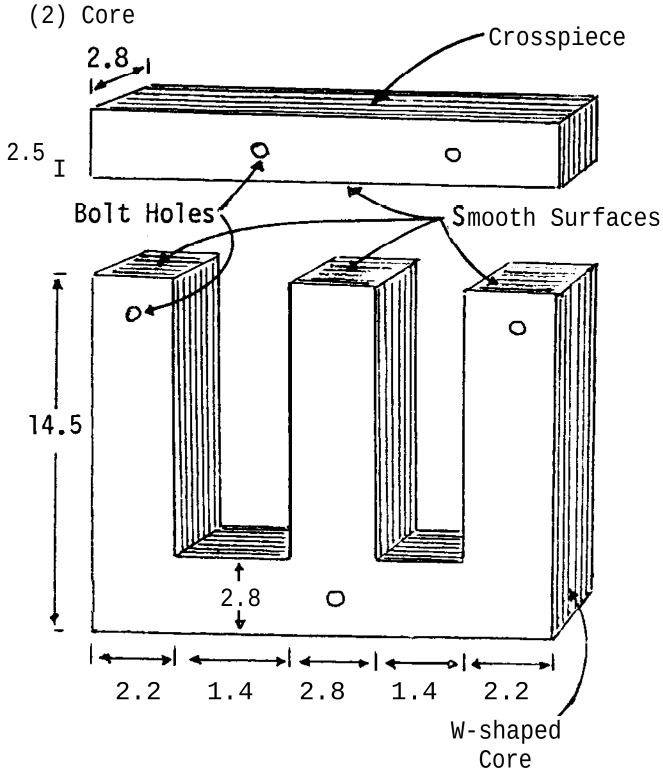
To make the primary coil, wind 720 turns (approximately 250 g) of magnet wire (B), onto the cardboard form. Each layer of turns will be 10 cm long. Place masking tape between each layer. The actual method of winding is described under VII/Al.



To make the secondary coil, wind 180 turns (approximately 250 g) of magnet wire (C) on top of the primary coil in the usual way (leaving a free end about 20 cm long at the start). However,



(2) Core



halt after every 30 turns to make a tap. (The latter is made by taking the next 40 cm of wire, folding it to make a double strand, and twisting it around itself.) Then continue for another 30 turns before making a further tap, again with a 40 cm length of wire. It is very important to make the taps at the corners of the secondary coil, otherwise they will interfere with the placement of the coil on the core. Each layer of turns should be covered in the usual way with masking tape to insulate it from the next layer. In all, there should be taps after 30, 60, 90, 120 and 150 turns, and a free end (20 cm long) after 180 turns.

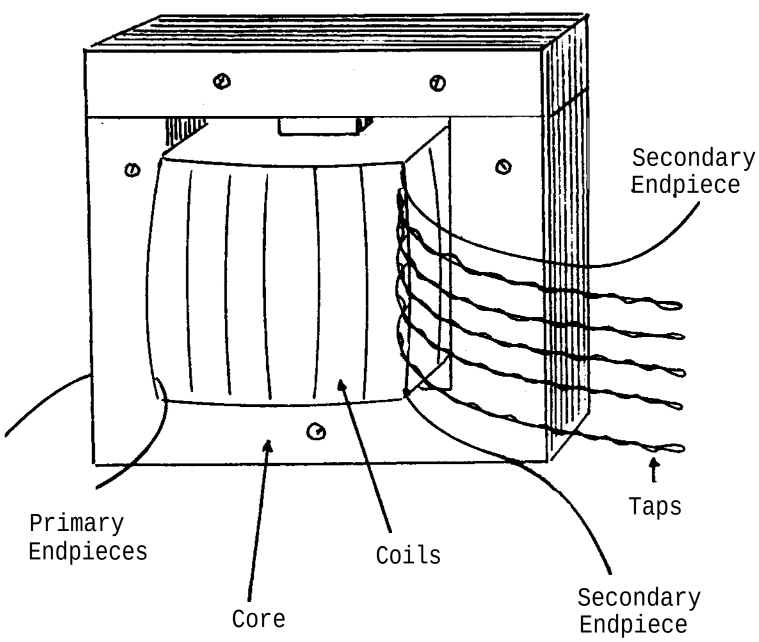
Stack the galvanized iron sheets (E) on top of the other until the pile is 2.8 cm thick. This will require 55, or more, plates, dependent on the thickness of the sheet. Then cut each of the sheets as illustrated to form a W-shaped plate and a rectangular crosspiece.

Stack the newly cut plates back on top of each other, and drill 5 bolt holes (diameter 0.4 cm) through the plates. A drill press is preferred for this purpose, but it is possible to hand drill each plate separately. Use nuts (G) and bolts (F) to fasten the plates of the crosspiece and core together.

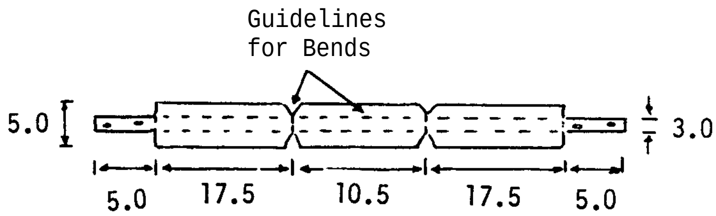
Take a file to smooth off the rough edges of the newly made core. It is important that the finished surfaces should insure good contact between the top of the W-shaped core and the cross-piece.

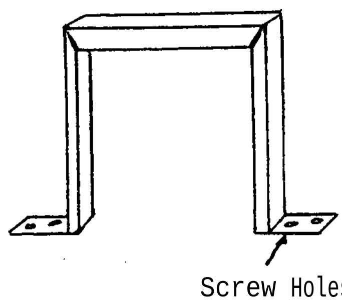
Now take the plates apart, and cover each in turn with varnish (H), reassembling the plates while still wet. The varnish acts as an insulator, which reduces eddy currents, and hence heating effects, within the core. The core may take one or two days to dry.

Assemble the coils on the W-shaped core, using paper or wood wedges if necessary to insure the coil is held firmly on the central upright of the core.

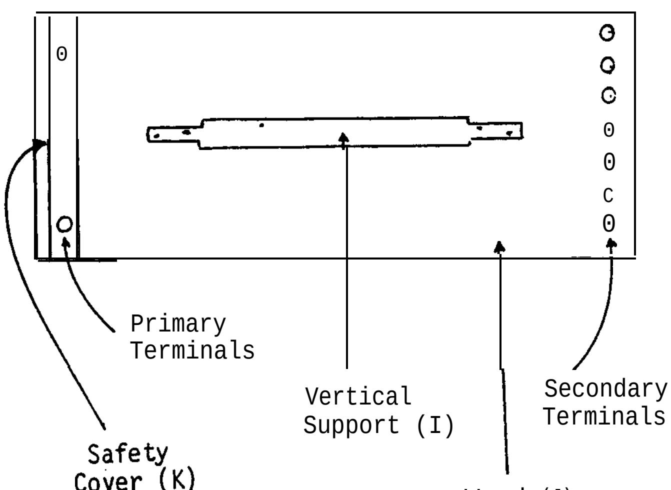


(3) Vertical Support

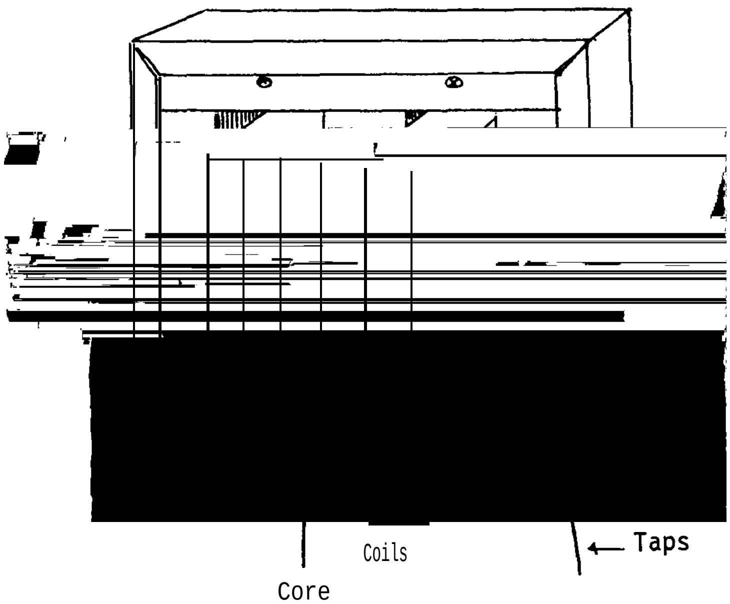




Use galvanized iron or aluminum sheeting (I) to make the vertical support. Cut it to the dimensions indicated, and bend it to the shape of a bridge. Drill two holes (diameter 0.3 cm) in either foot of the bridge so that the support may subsequently be attached to a base with screws.

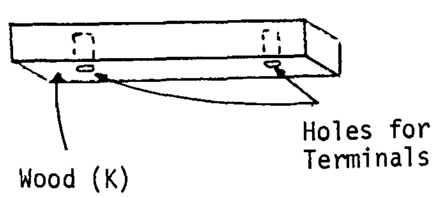


Make a base for the transformer out of wood (J). Fit the vertical support snugly over the core and coils, and attach the support to the middle of the base with screws.



Use bolts (L) and nuts (M) to make nine terminals [as described under VII/AZ, Component (4)]. Fit seven at one end of the base to serve as secondary terminals, and attach the ends of the secondary coil and the taps to these after cleaning the ends of the wire and taps with sandpaper. Cover the wires with insulation tape (N) or tubing to prevent any possibility of a short. Fit the other two terminals at the other end of the base to serve as the primary terminals. Attach the ends of the primary coil to the terminals after cleaning the ends of the wire with sandpaper. Remembering that the primary coil will be connected to the mains (120 volts), it is important to insure good insulation of all primary terminals and wires. Therefore, cover each of the wires from the primary coil to the relevant terminal with electrical insulation tape.

In addition, make a safety cover for the primary terminals from wood (K). Simply cut holes (2 cm deep, 1 cm diameter) in the undersurface to accommodate the terminals, and set the wood on the base so that it covers the terminals.



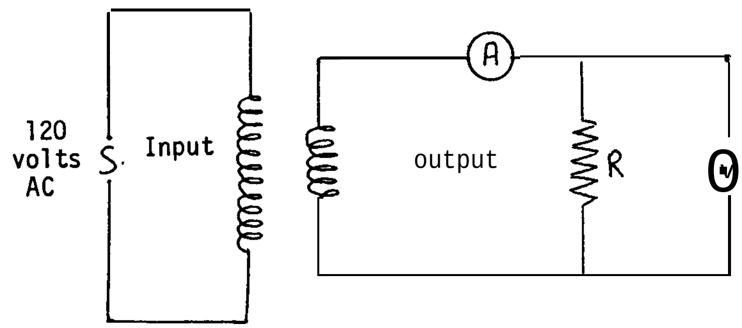
C. Notes

(i) Do not expect the output voltages to be exactly 5, 10, 15 volts and so on, With the apparatus produced and tested here the output voltages, observed by combining any one tap with the coil endpiece, were 4.5, 10.0, 15.0, 21.0, 26.3 and

31.0 volts when the primary voltage was 121 volts.

(ii) The transformer was tested using the 10, 20 and 30 volt outputs. As expected, it was noted that the transformer operated more efficiently at the higher voltages.

The voltage output from any given pair of terminals was observed to fall as the current output increased. Actual results are tabulated below.



Output Taps - 30 volts

Input	output				
*Power Watts	I Amps	V Volts	R Ohms	*Power Watts	Efficiency %
46	1.00	28.4	28.4	28.40	62
52	1.25	28.0	22.4	35.00	67
59	1.50	27.5	18.3	41.25	70
68	1.75	27.0	15.4	47.25	69
75	2.00	26.5	13.2	53.00	71
82	2.25	26.0	11.5	58.50	71
90	2.50	25.5	10.2	63.75	71
97	2.75	25.0	9.1	68.75	71
105	3.00	24.0	8.0	72.00	69

* Power was measured directly with wattmeters.

Output Taps = 20 volts

Input	output				
*Power Watts	I Amps	V Volts	R Ohms	*Power Watts	Efficiency %
33	0.75	19.5	26.0	14.6	44
3a	1.00	19.2	19.2	19.2	50
43	1.25	19.0	15.2	23.7	55
4a	1.50	la.5	12.3	27.7	5a
52	1.75	la.3	10.4	32.0	61
56	2.00	la.0	9.0	36.0	64
61	2.25	17.7	7.9	39.a	65
66	2.50	17.5	7.0	43.7	66
71	2.75	17.0	6.2	46.7	66
76	3.00	16.5	5.5	49.5	65

Output Taps = 10 volts

Input	output				
*Power Watts	I Amps	V Volts	R Ohms	*Power Watts	Efficiency %
22	0.50	9.0	18.0	4.5	20
24	0.75	a.a	11.7	6.6	27
26	1.00	a.7	a.7	a.7	33
29	1.25	8.6	6.9	10.7	37
31	1.50	a.4	5.6	12.6	41
34	1.75	a.3	4.7	14.5	43
36	2.00	a.1	4.0	16.2	45
3a	2.25	a.0	3.5	18.0	47
40	2.50	7.a	3.1	19.5	49
43	2.75	7.7	2.a	21.2	49
45	3.00	7.6	2.5	22.a	51

* Power was measured directly with wattmeters.

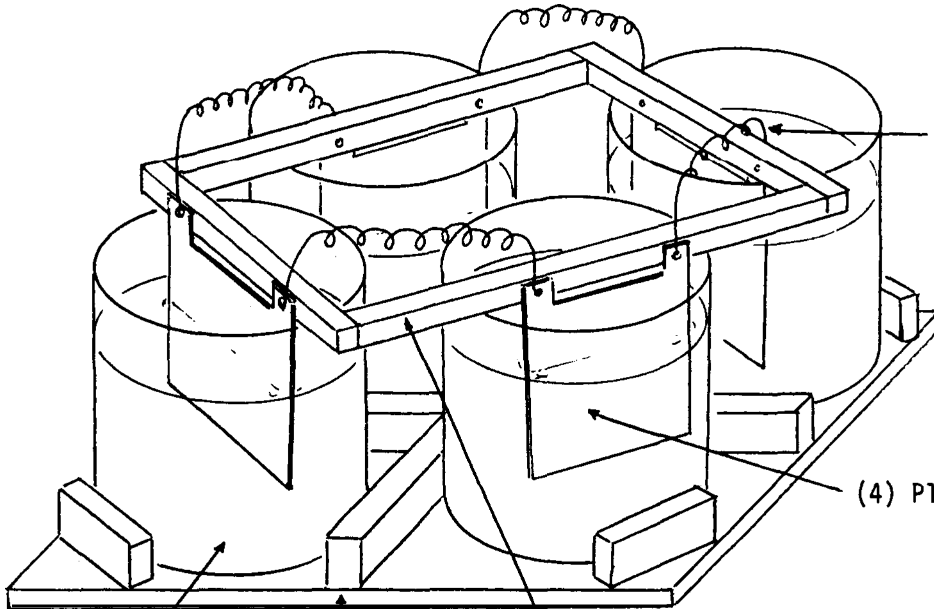
(iii) Some heating of the transformer was noted,but this appeared to be within acceptable limits. Hence, when a current of 3 amps was drawn from the maximum voltage taps (30 volts) the temperature of the transformer core did not rise beyond 60° Centigrade.

Output Taps = 30 volts
output = 3 amps at 24 volts
Room Temperature = 24°C

Running Time (Minutes)	Core Temperature (Degrees Centigrade)
0	27° C
5	38° C
10	48° C
15	49° C
20	51° C
25	53° C
40	56° C
50	58° C
60	59° C

B. RECTIFIERS

Bl. Sodium Bicarbonate Rectifier (2 Plate)



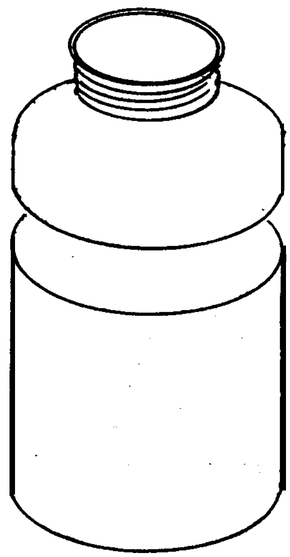
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Cell Containers	4	Glass Jars (A)	Approximately 300 ml, 10 cm diameter
(2) Base	1	Plywood Sheet (B)	22 cm x 22 cm x 0.5 cm
	1	Wood Strip (C)	22 cm x 2 cm x 2 cm
	2	Wood Strips (D)	10 cm x 2 cm x 2 cm
	4	Wood (E)	2 cm x 2 cm x l cm
(3) Plates Support	2	Wood (F)	15 cm x 1.5 cm x 1.5 cm
	2	Wood (G)	12 cm x 1.5 cm x 1.5 cm
(4) Plates	4	Lead Sheets (H)	6.5 cm x 5.0 cm x 0.02 cm
	4	Aluminum Sheets (I)	6.5 cm x 5.0 cm x 0.02 cm
	8	Bolts (J)	0.3 cm diameter, 2.5 cm long
	a	Nuts (K)	0.3 cm internal diameter

	16	Washers (L)	0.3 cm internal diameter, approximately
	4	Filter Papers (M)	5.5 cm x 5.5 cm
	1	Saturated Solution of Sodium Bicarbonate (N)	1 liter
(5) Wiring	1	Roll of Magnet Wire (0)	#24

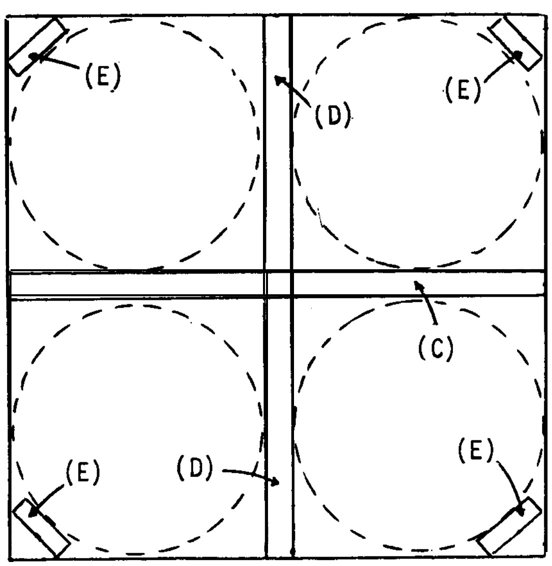
c. Construction

(1) Cell Containers



To make a cell container, take jar (A), and use a hot nichrome wire (CHEM/I/F2) to cut the top off the jar some 6 cm above the base. Repeat the process with three more jars.

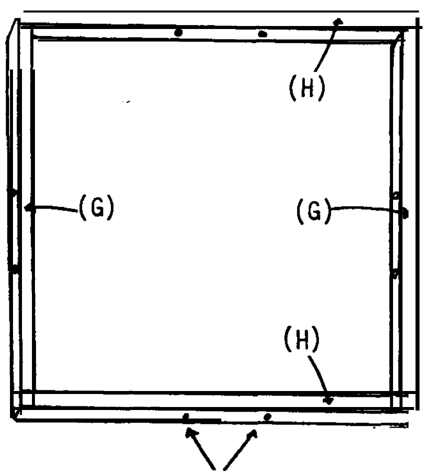
(2) Base



Plywood Base (B)

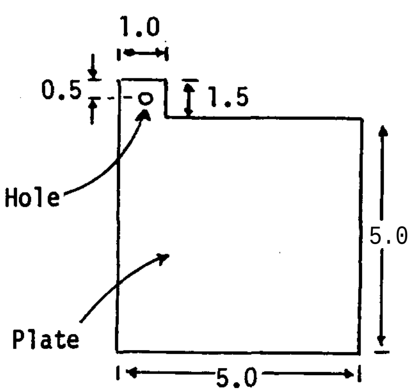
Nail wood strips (C,D) to the top of the plywood sheet (B) so as to divide it into four equal portions. Nail the wood strips (E) at the corners of the plywood in such a way that the four cell containers, placed in the appropriate quarters, will be held in position on the plywood base.

(3) Plates Support

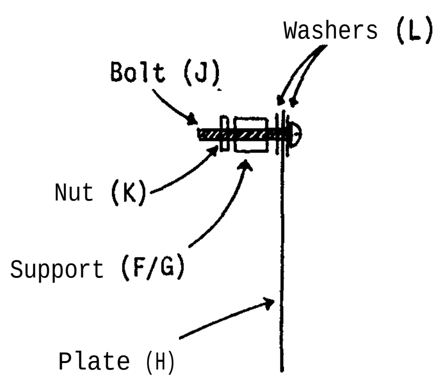


Use wood Strips (F) and (G) to make the frame of the plate support. Drill two bolt holes (0.3 cm diameter) in each side of the support, such that the holes in any one side are 4 cm apart, and are equidistant from the center of the side.

(4) Plates



Cut a plate out of lead sheeting (H) and another out of aluminum sheeting (I) to the dimensions shown. Drill a hole (0.3 cm diameter) in the projecting portion of each plate.



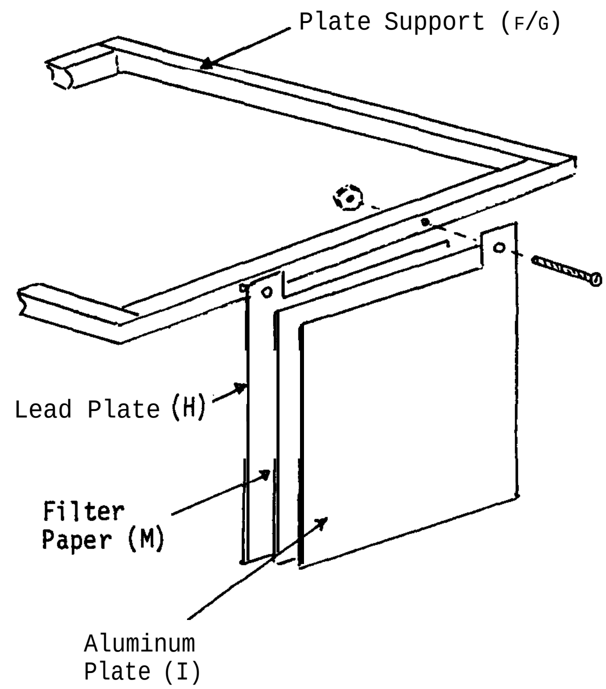
Attach the lead plate to the plate support with the help of bolt (J), nut (K) and washers (L) placed either side of the plate.

Attach the aluminum plate to the plate support in the same way, but so that the aluminum plate lies on top of the lead plate. Place the sheet of filter paper (M) between the two plates, thus insulating one from the other,

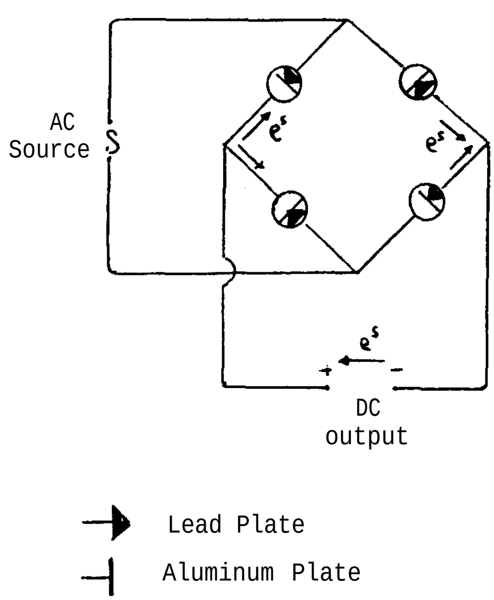
Cut three more lead plates and three more aluminum plates, and make identical plate pairs (insulated with filter paper) for the three remaining sides of the plate support.

Rest the plate support on the four cut jars, such that one pair of plates is suspended in each jar.

Almost fill each jar with a saturated solution of sodium bicarbonate (N),that is baking soda, and add a little extra sodium bicarbonate to each cell to insure that the solution remains saturated during use.



(5) Wiring

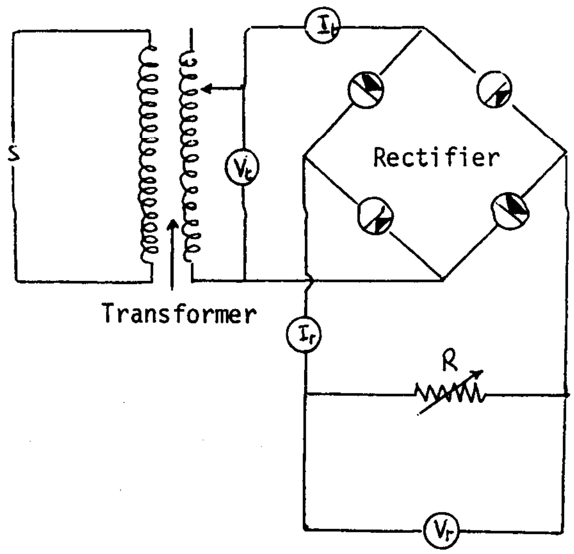


Use copper wire (0) to connect the plates of the four cells together, as indicated in the diagram. The cells have the simple property of permitting electrons to flow only in one direction, from aluminum to lead, and when connected as indicated to an AC source a rectified output is obtained. The type of output obatined with AC sources of 12 volts and 25 volts is indicated in the notes.

c. Notes

(i) The AC voltage supply may be taken from the transformer already described (VII/A3). A series of tests were conducted on the rectifier produced here, after it had been running for one hour. The results are tabulated below.

(ii) With a variable resistance (R) connected across the DC output it will be noted that the output voltage (V_r) fell off as the resistance decreased. [A very small proportion of the fall in voltage may be attributed to the drop in voltage (V_t) from the transformer.]



AC Supply = 15 volt taps

Load	Transformer Output			Rectifier Output			Efficiency
R Ohms	V_t Volts	I_t Amps	W_t Watts	V_r Volts	I_r Amps	W_r Watts	%
820	15.7	0.10	1.57	8.2	0.01	0.08	5.2
800	15.6	0.11	1.71	8.0	0.01	0.08	4.7
390	15.6	0.15	2.34	7.8	0.02	0.16	6.7
172	15.5	0.20	3.10	6.9	0.04	0.28	8.9
98	15.5	0.21	3.26	5.9	0.06	0.35	10.8
84	15.4	0.25	3.86	5.9	0.07	0.41	10.7
70	15.3	0.30	4.59	5.6	0.08	0.45	9.8
60	15.3	0.30	4.59	5.4	0.09	0.49	10.6
52	15.3	0.30	4.59	5.2	0.10	0.52	11.3
42	15.2	0.30	4.56	5.0	0.12	0.60	13.2
31	15.1	0.35	5.28	4.6	0.15	0.69	13.1
21	15.1	0.45	6.80	4.2	0.20	0.84	12.3
11	15.0	0.61	9.15	3.4	0.31	1.05	11.5
9	14.9	0.75	11.18	3.2	0.37	1.18	10.6
6	14.8	0.95	14.06	2.8	0.45	1.26	8.9
5	14.5	1.05	15.23	2.6	0.50	1.30	8.5
3	14.0	1.35	18.90	1.9	0.68	1.29	6.8

AC Supply = 25 volt taps

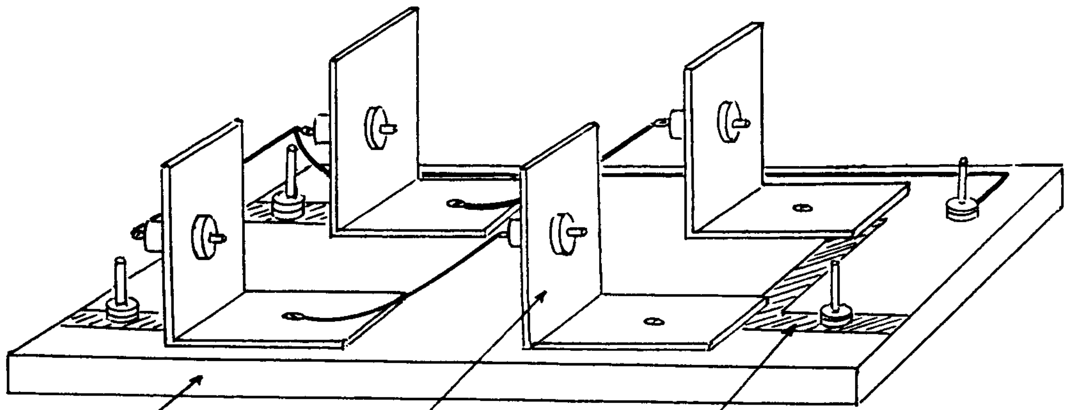
Load	Transformer Output			Rectifier Output			Efficiency
R Ohms	V_t Volts	I_t Amps	W_t Watts	V Volts	I_r Amps	W_r Watts	%
1,850	25.9	0.48	12.43	la.5	0.01	0.18	1.5
910	25.9	0.48	12.43	la.2	0.02	0.36	2.9
583	25.9	0.50	12.95	17.5	0.03	0.53	4.1
435	25.9	0.50	12.95	17.4	0.04	0.70	5.4
275	25.8	0.55	14.19	16.5	0.06	0.99	7.0
200	25.8	0.60	15.48	16.0	0.08	1.28	a.3
97	25.2	0.70	17.64	14.5	0.15	1.45	a.2
a9	25.1	0.75	la.82	14.2	0.16	2.27	12.1
78	25.1	0.78	19.58	14.0	0.18	2.52	12.9
69	25.0	0.80	20.00	13.8	0.20	2.76	13.8
61	25.0	0.85	21.25	13.5	0.22	2.97	14.0
50	24.8	0.95	23.56	13.0	0.26	3.38	14.4
39	24.5	1.05	25.73	12.5	0.32	5.00	19.4
30	24.0	1.22	29.28	12.0	0.40	4.80	16.4
20	23.5	1.52	35.72	11.0	0.55	6.05	16.9
10	22.2	2.15	47.73	9.0	0.88	7.82	16.4

(iii) The current output of the rectifier was very low, but was noted to increase when the voltage from the transformer was increased. Thus with a resistance of 10 ohms in the external circuit the DC current produced was 0.34 or 0.88 amps according to whether the rectifier was connected to the 15 or 25 volt taps on the transformers.

(iv) The rectifier was extremely inefficient in its use of power. The maximum efficiency on the 15 volt taps was noted to be 13% and on the 25 volt taps to be 19%.

(v) It was noted that not only did the output voltage (V_r) from the rectifier decrease with increasing resistance (R), but that there was also some variation of the voltage (V_r) at a fixed resistance (R) with the passage of time. These factors suggest that although the apparatus is capable of producing a DC current, the latter is not suitable for quantitative (as opposed to qualitative) experimentation.

B2. Silicon Rectifier



a. Materials Required

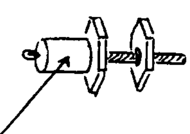
Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	15 cm x 10 cm x 2 cm
(2) Rectifiers and Supports	4	Silicon Rectifier Diodes (B)	1N1341
	4	Brass Bars (C)	7 cm x 2 cm x 0.3 cm
(3) Electrical Connections	2	Brass Strips (D)	5 cm x 1 cm x 0.5 cm
	1	Brass Strip (E)	5 cm x 3 cm x 0.5 cm
	4	Bolts (F)	0.3 cm diameter, 3.5 cm long
	8	Nuts (G)	0.3 cm internal diameter
	1	Copper Wire (H)	#20, 40 cm long

b. Construction

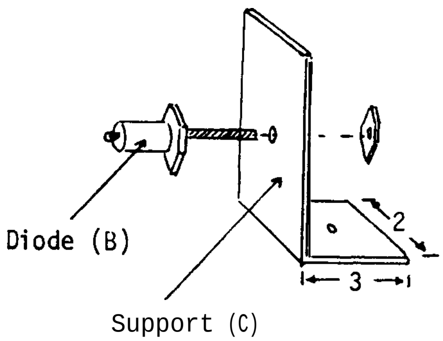
(1) Base

Use wood (A) as the base.

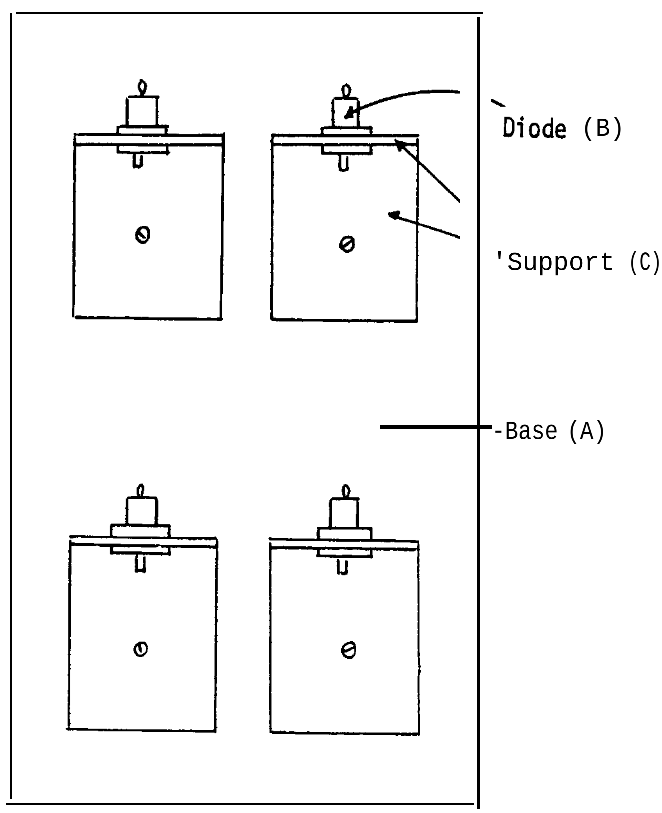
(2) Rectifiers and Supports



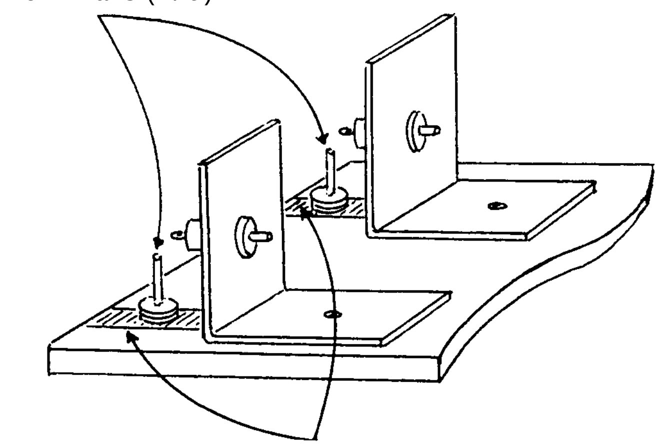
Purchase four silicon rectifier diodes (B) from a radio shop or electrical supply house. Ask for a rectifier identified as a 1Nl341. This will be capable of handling a peak reverse voltage of 50 volts, a continuous forward current of 6 amps and a maximum surge of 30 amps.



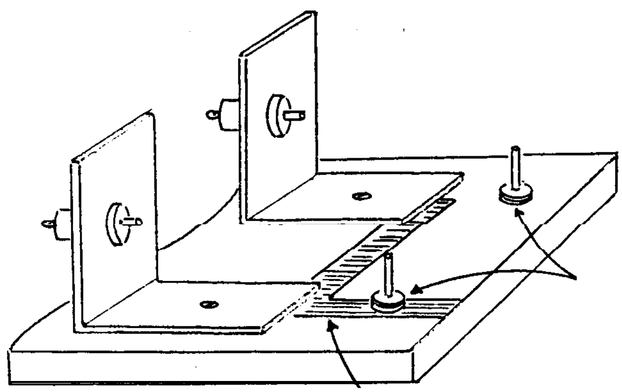
Take a brass bar (C) and bend it at right angles, 4 cm from one end, to form an L-shaped support. Drill a hole (0.5 cm diameter) in the middle of the long upright of the support and a hole (0.3 cm diameter) in the base of the support. Screw one of the rectifier diodes in the upright portion of the support. Attach the three remaining diodes (B) to three identical supports (C) in the same way. Attach the four supports to the base (A). It should be noted that the supports also act as heat sinks, removing heat that is generated within the diodes. It is for this reason that the support is made from a thick metal bar.

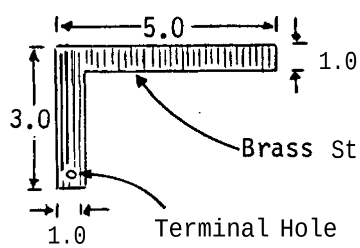


(3) Electrical Connections

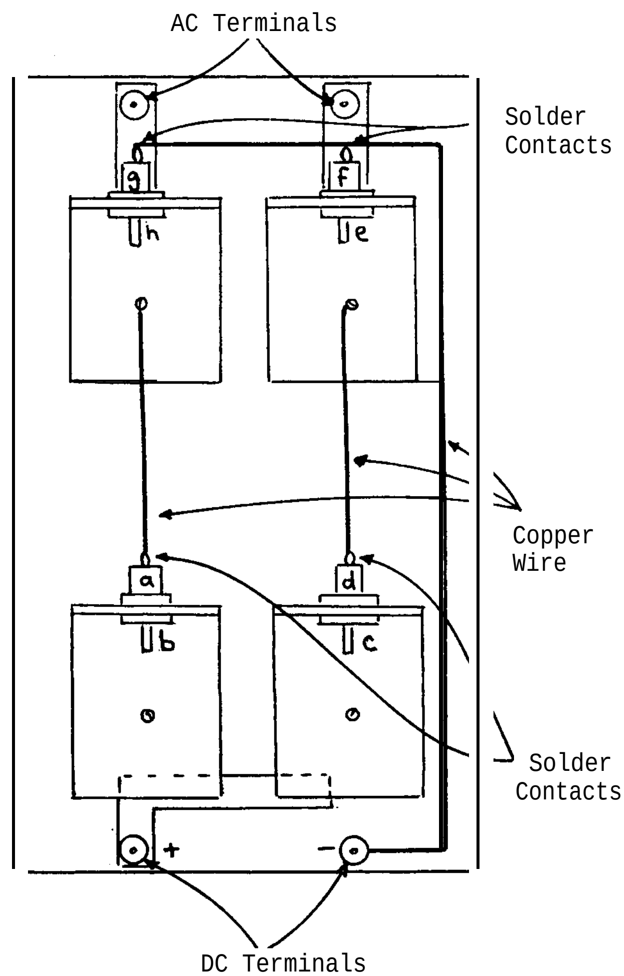


Take the two brass strips (D) and drill a hole (0.3 cm diameter) close to the end of each. Insert the strips under the supports (C) at one end of the base as indicated. Use bolts (F) and nuts (G) to make four terminals (F/G) as described under VIII/A2,Component (4). Fit two of the terminals on the base so that each is connected to a brass strip by means of the appropriate hole.





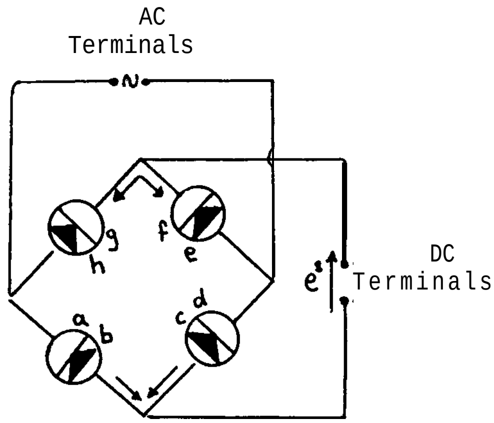
Cut an L-shaped strip out of brass sheet (E). Drill a hole (0.3 cm diameter) in the end of the shorter arm, and fit the longer arm beneath the two remaining supports so that they are connected electrically. Fit Terminals the two remaining term. (F/G) to the end of the base, so that one is connected to the L-shaped strip.



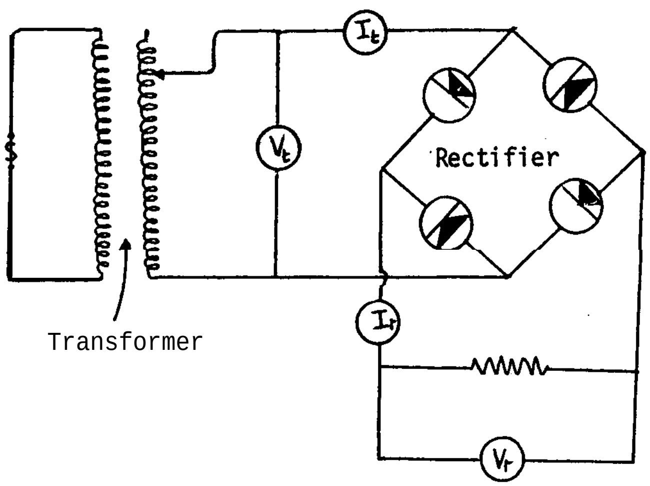
Take the copper wire (H) and connect the silicon diodes as illustrated. It will be necessary to solder the wire on to the ends of the diodes, and particular care should be taken to avoid overheating, since this can destroy the diodes.

C. Notes

(i) The rectifier produced is represented diagrammatically here. The reader should compare this with the previous diagram, noting the equivalent components marked by letters of the alphabet.



(ii) With a variable resistance R connected across the DC output it will be noted that the output voltage (V_r) falls off as the resistance decreases, even when the transformer is continuously monitored to keep the voltage (V_t) constant. This pattern of behavior is the same as for, the Sodium Bicarbonate Rectifier (VII/Bl). However, it will be noted that the efficiency of the Silicon Rectifier varies from 60% to 70% and the rectified current is as great as 3 amps at 5.5 volts. In this respect the Silicon Rectifier is a considerable improvement over the Sodium Bicarbonate Rectifier.



AC Supply = 10 volt taps

Load	Transformer Output			Rectifier Output			Efficiency
R Ohms	V_t Volts	I_t Amps	W_t Watts	V_r Volts	I_r Amps	W_r Watts	%
110	10.2	0.08	0.82	7.7	0.07	0.6	70.4
96	10.2	0.09	0.92	7.7	0.08	0.6	67.4
86	10.2	0.10	1.02	7.7	0.09	0.7	67.9
77	10.2	0.11	1.12	7.7	0.10	0.8	68.7
63	10.2	0.13	1.33	7.6	0.12	0.9	68.6
54	10.1	0.16	1.62	7.6	0.14	1.1	67.9
42	10.1	0.20	2.02	7.6	0.18	1.4	67.7
31	10.1	0.26	2.63	7.5	0.24	1.8	68.4
21	10.0	0.39	3.90	7.4	0.35	2.6	66.7
11	9.9	0.77	7.62	7.2	0.68	4.9	64.2
9	9.8	0.90	8.82	7.0	0.80	5.6	63.5
8	9.8	1.00	9.80	7.0	0.86	6.0	61.2
7	9.7	1.15	11.20	7.0	1.00	7.0	62.5
5	9.6	1.42	13.60	6.8	1.35	8.5	62.3
4	9.4	1.68	15.80	6.6	1.50	9.9	62.6
3	9.3	1.95	18.10	6.4	1.75	11.2	61.9
2	8.7	3.05	26.50	5.8	2.75	15.9	60.2
1	8.6	3.35	28.80	5.6	3.00	16.8	58.3

AC Supply = Held constant at 10 volts.

Load	Transformer Output			Rectifier Output			Efficiency
R Ohms	V_t Volts	I_t Amps	W_t Watts	V_r Volts	I_r Amps	W_r Watts	%
128	10.0	0.06	0.60	7.7	0.06	0.46	76.7
95	10.0	0.08	0.80	7.6	0.08	0.60	75.0
63	10.0	0.13	1.30	7.6	0.12	0.91	70.0
38	10.0	0.22	2.20	7.6	0.20	1.52	69.1
25	10.0	0.32	3.20	7.6	0.30	2.28	7.13
19	10.0	0.43	4.30	7.5	0.40	3.00	69.8
15	10.0	0.55	5.50	7.5	0.50	3.75	68.2
12	10.0	0.66	6.60	7.5	0.60	4.50	68.2
9	10.0	0.89	8.90	7.4	0.80	5.92	66.5
7	10.0	1.07	10.70	7.4	1.02	7.55	70.6
6	10.0	1.32	13.20	7.3	1.25	9.13	69.2
5	10.0	1.61	16.10	7.3	1.51	11.02	68.4
4	10.0	1.88	18.80	7.2	1.75	12.60	67.0
3	10.0	2.41	24.10	7.2	2.25	16.20	67.2
2	10.0	3.27	32.70	7.1	3.00	21.30	65.1

(iii) The output voltage (V_r) remains extremely steady with the passage of time, making this a much more suitable rectifier for quantitative experimentation than the Sodium Bicarbonate Rectifier.

AC Supply = 10 volt taps

Time	Transformer Output		Rectifier Output	
t Minutes	V_t Volts	I_t Amps	V_r Volts	I_r Amps
1	9.5	1.62	6.6	1.50
2	9.5	1.62	6.6	1.49
3	9.6	1.63	6.6	1.50
4	9.6	1.62	6.6	1.50
5	9.7	1.63	6.6	1.51
10	9.7	1.63	6.6	1.51
15	9.7	1.63	6.6	1.51
20	9.7	1.63	6.6	1.51
25	9.7	1.63	6.6	1.51
30	9.8	1.65	6.6	1.51

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

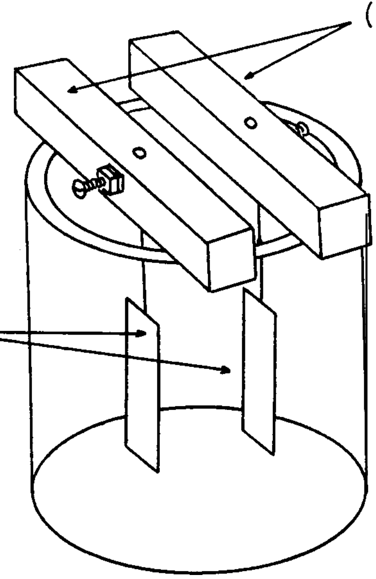
Fixed and variable resistors for typical classroom experiments are described in this section.

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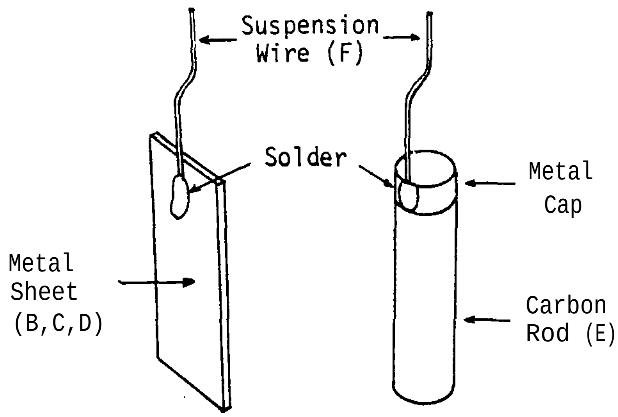
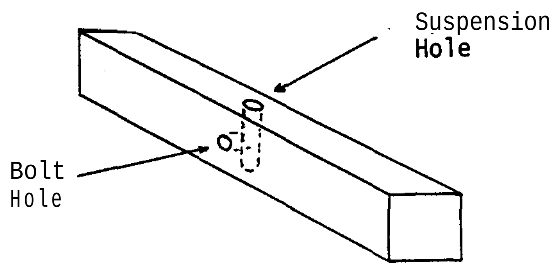
may be used, including commonly available vinegar and household salt solutions.)

(2) Plates

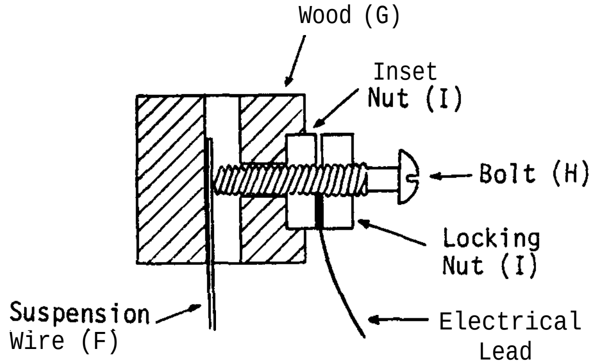


Solder a brass suspension wire (F) on to each of the metal sheets (B, C and D). Also solder a similar suspension wire (F) to the metal cap on a carbon rod (E) extracted from a dry cell.

(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

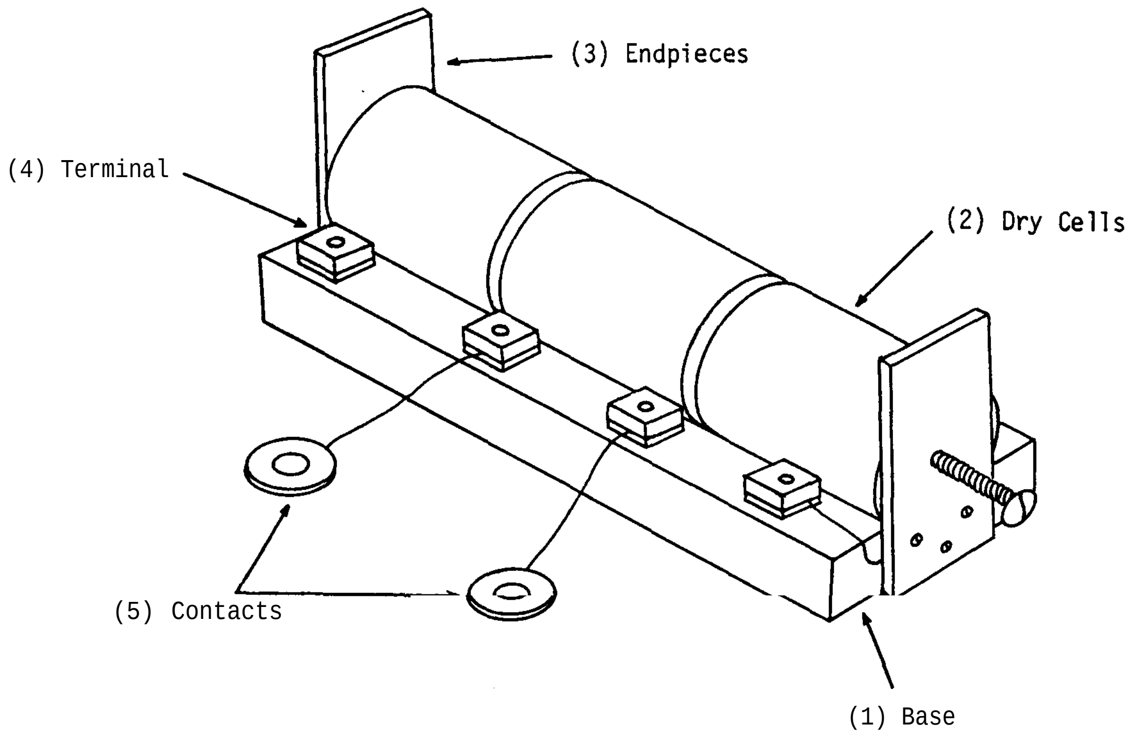
Inset one of the nuts (I) over the bolt hole with a sharp tap of the hammer (A little epoxy resin will hold the nut permanently in position.) Thread the second nut (I) on to the bolt (H) to serve as a locking nut, and then screw the bolt into the bolt hole. Insert a suspension wire in the vertical hole,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

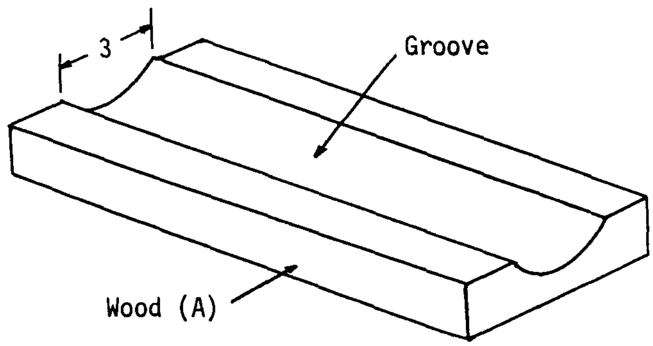
Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	18.5 cm x 5.5 cm x 2 cm
(2) Cells	3	Dry Cells (B)	1.5 volts each
(3) Endpieces	2	Brass Sheets (C)	4.0 cm x 1.5 cm x 0.3 cm
	6	Screws (D)	Approximately 0.8 cm long
	1	Bolt (E)	0.4 cm diameter, 2 cm long
	1	Nut (F)	0.4 cm internal diameter
(4) 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

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London:: Center for Educational Development Overseas, 1972), pp 123-127.

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

b. Construction

(1) Base

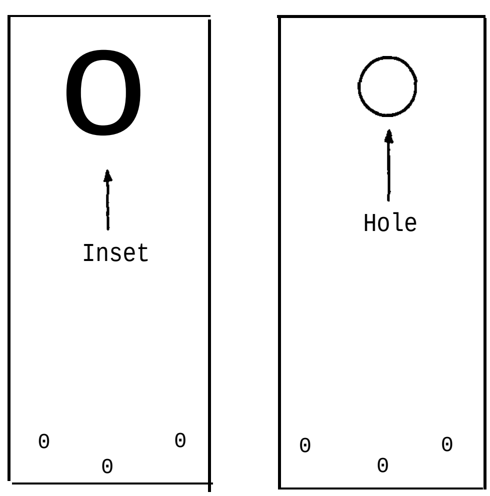


Cut the base out of the soft wood (A), and use a curved chisel to make a long groove (about 0.5 cm deep) in the surface to hold the dry cells in position.

(2) Cells

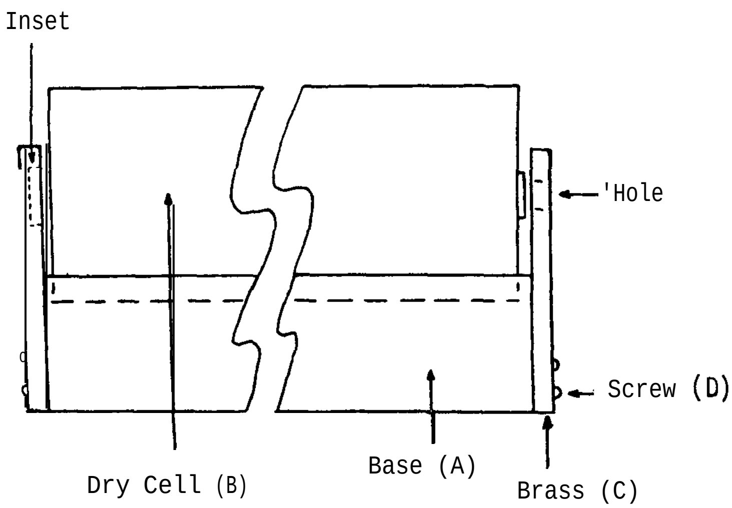
Place three dry cells (B) in series in the groove of the base. The groove should be from 1 to 1.5 cm longer than the three cells placed end to end, thus allowing room for the placing of contacts between the cells, and for adjustment of the screw in one of the end-pieces.

(3) Endpieces

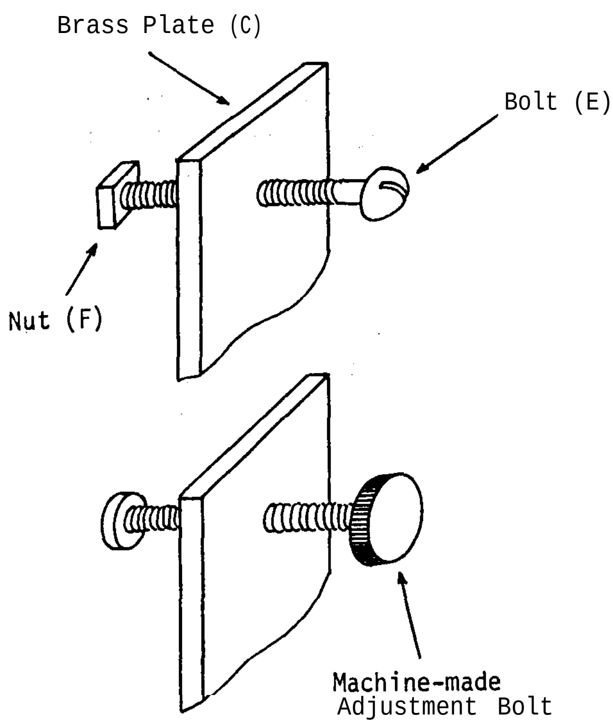


8rass Plates (C)

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).

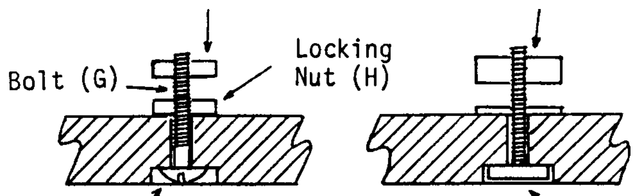


Side View



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

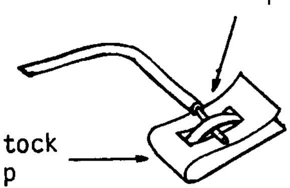


Side View

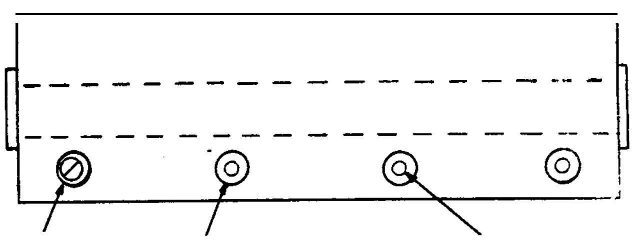
(Cross-section)

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.

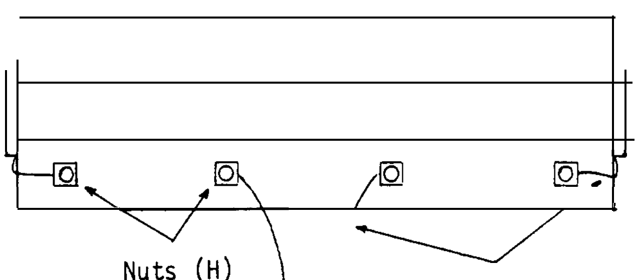
Somewhat better nuts, which are more easily adjusted with the fingers, may be made with a metal lathe. The terminal nut should be 0.5 cm thick, while the locking nut should be much thinner (0.2 cm). The diameter of both should be 1.0 cm.



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



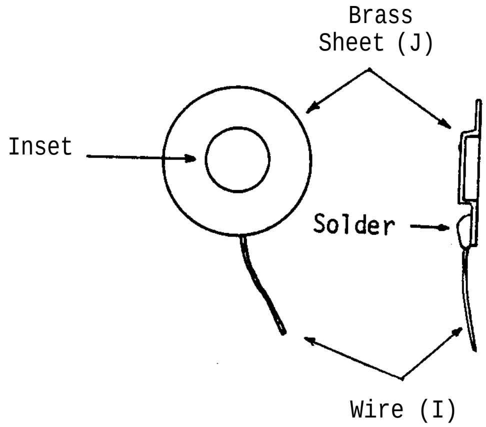
Base, Top View

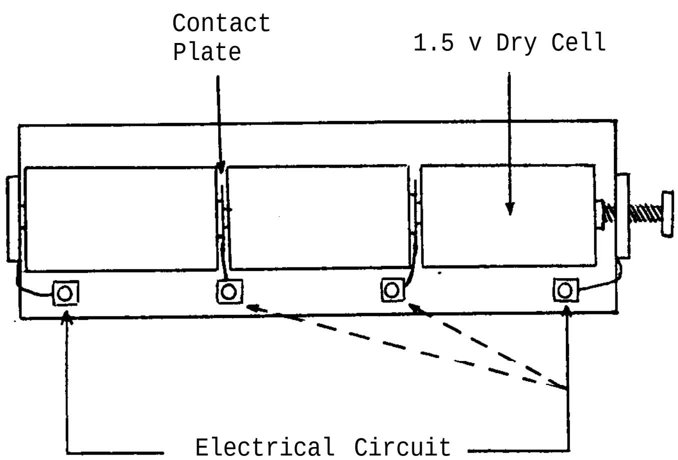
Make four insets (0.2 cm deep) at equal intervals underneath the front side of the base to take the boltheads of the terminals. Insert the four bolts (G) from below, through holes drilled through the base, and attach the locking nuts (H) and terminal nuts (H).

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

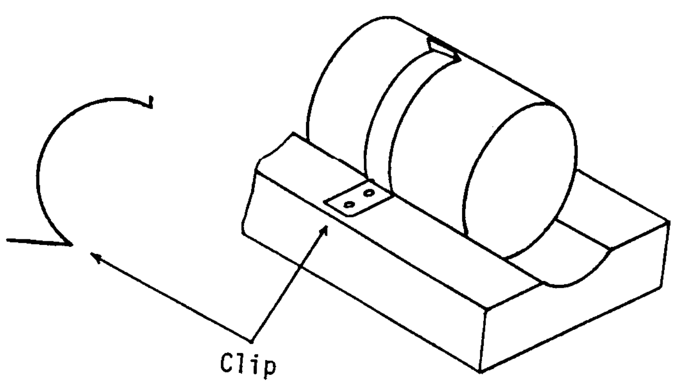
Use a nail head, or punch, to make a central inset (1 cm diameter, 0.2 cm deep) in the two brass sheets (J). Solder the two plates to the bare ends of the wire (I) attached to the two middle terminals. The contact plates are placed between the first and second, and second and third cells, thus enabling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





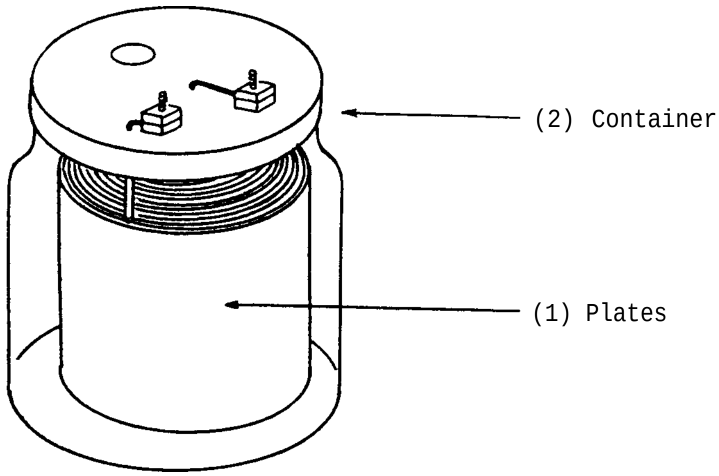
C. Notes

(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 *



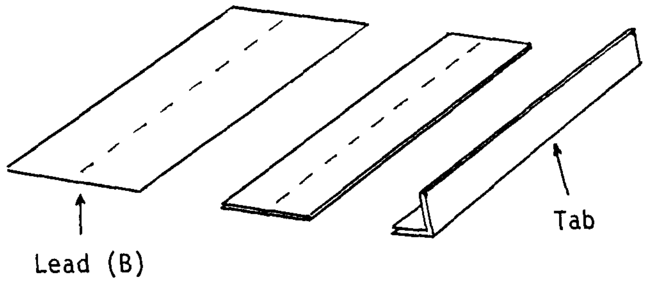
a. Materials Required

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

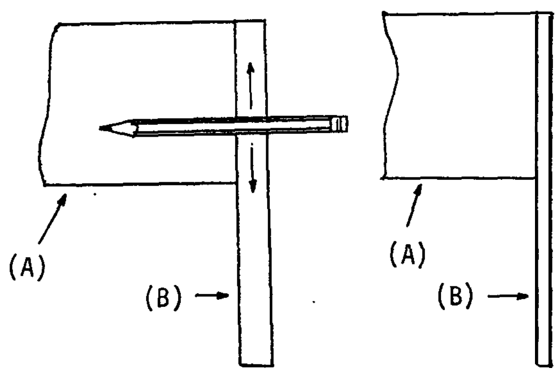
*Adapted from Intermediate Science Curriculum Study, Probing the Physical World, Volume 1, Experimental Edition, (Tallahassee, Florida: Florida State University, 1967), pp l-4.

b. Construction

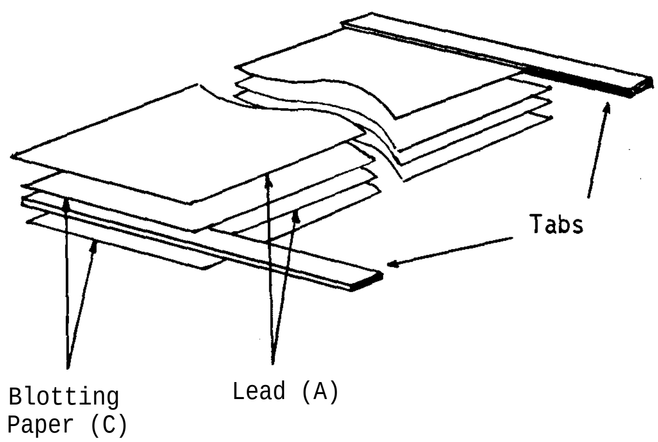
(1) Plates



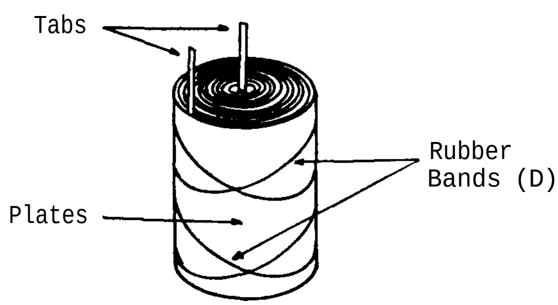
Fold one of the small lead sheets (B) down the middle. Repeat the process again, but this time leave the fold open. You now have a tab for attachment to one of the lead plates.



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).

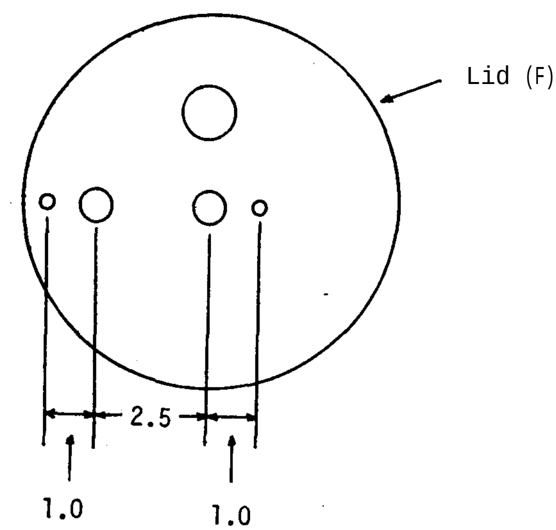


Make a plate "sandwich" by placing the blotting paper (C), lead plate, blotting paper (C), lead plate one on top of the other. The tabs should be at opposite ends of the sandwich, but emerging from the same side.

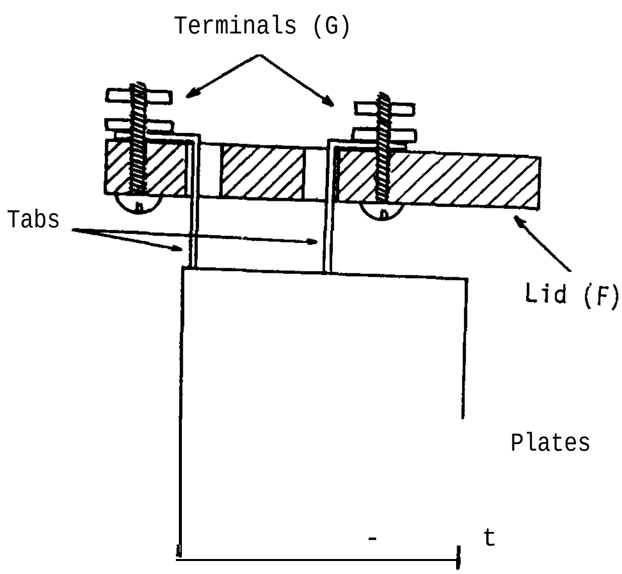


Roll the "sandwich" up into a tight cylinder. One tab will protrude from the center and one from the edge. Hold the plates in the form of a cylinder by wrapping the rubber bands (D) around the cylinder.

(2) Container



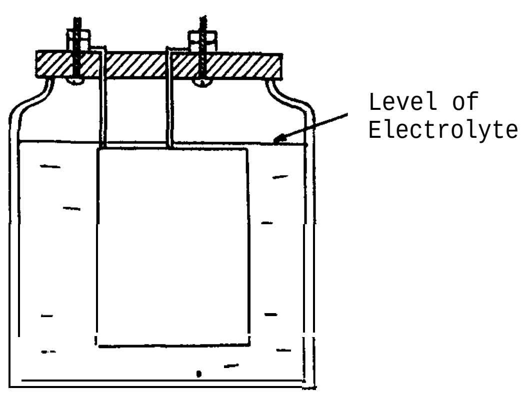
Obtain a one liter jar (E), and use the plywood lid (F) to cover the open end of the jar. Bore two holes (0.5 cm diameter) through the lid to accommodate the tabs, one hole being at the center of the lid and the other 2.5 cm away from the first hole. Drill two more holes (0.3 cm diameter), one on either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

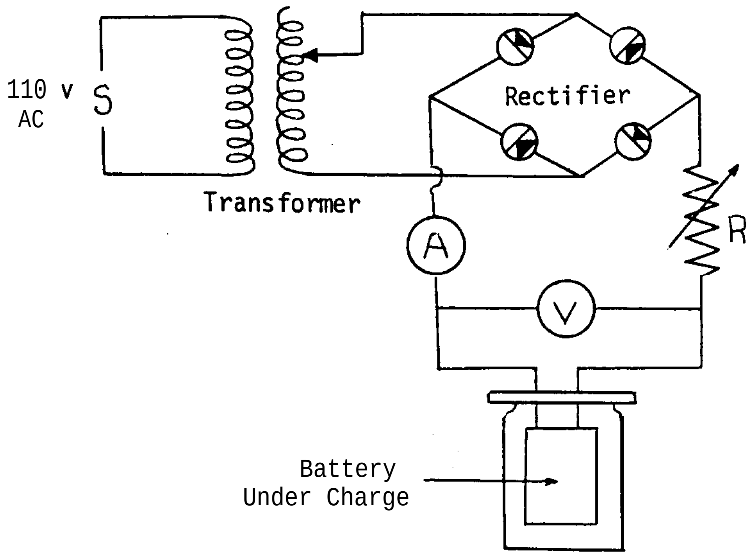
To make the sulphuric acid electrolyte pour 813 ml of water into a container. Then add 187 ml of concentrated sulphuric acid (H) to the water in very small quantities, letting the acid run down the sides of the container into the water. Much heat will be caused by the inter action. Stir the electrolyte, 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 pre-ferred 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.

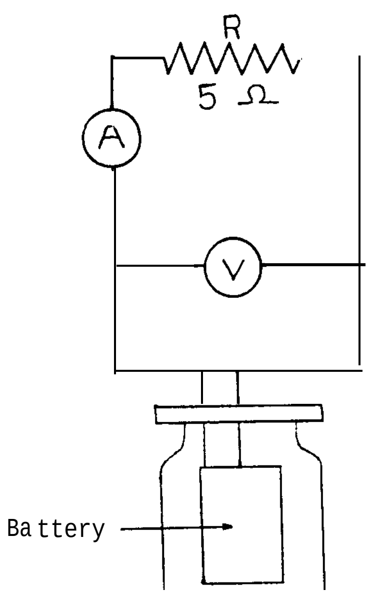
C. Notes

(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

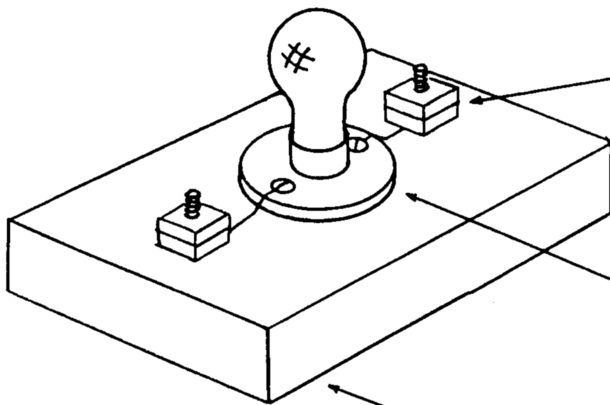
(iv) Some idea of the strength of the battery is obtained by comparing the discharge of a small dry cell (through a five ohm resistor) with the above observations. The results indicate that the dry cell is not as steady a source of current and voltage as the battery after successive recharging, but that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

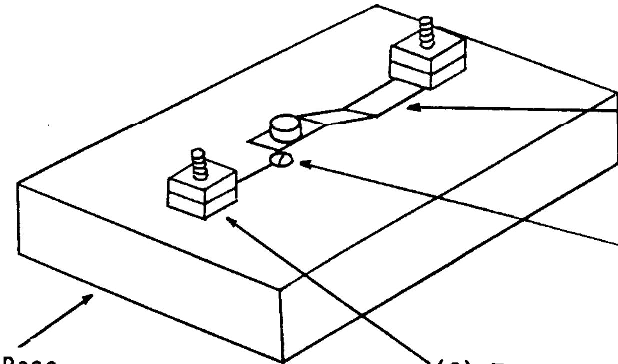
(3) Terminals

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 cm x 3 cm x 1 cm
(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

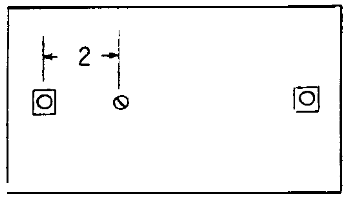
(1) Base

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).

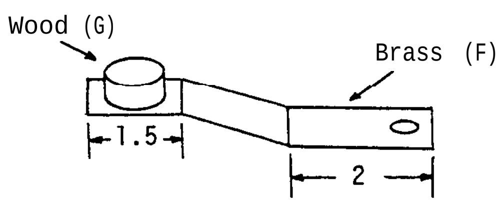
(3) Contact Point

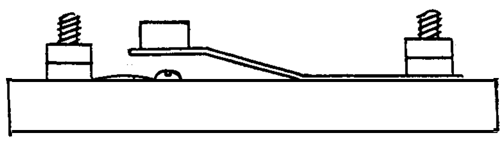


Top View

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

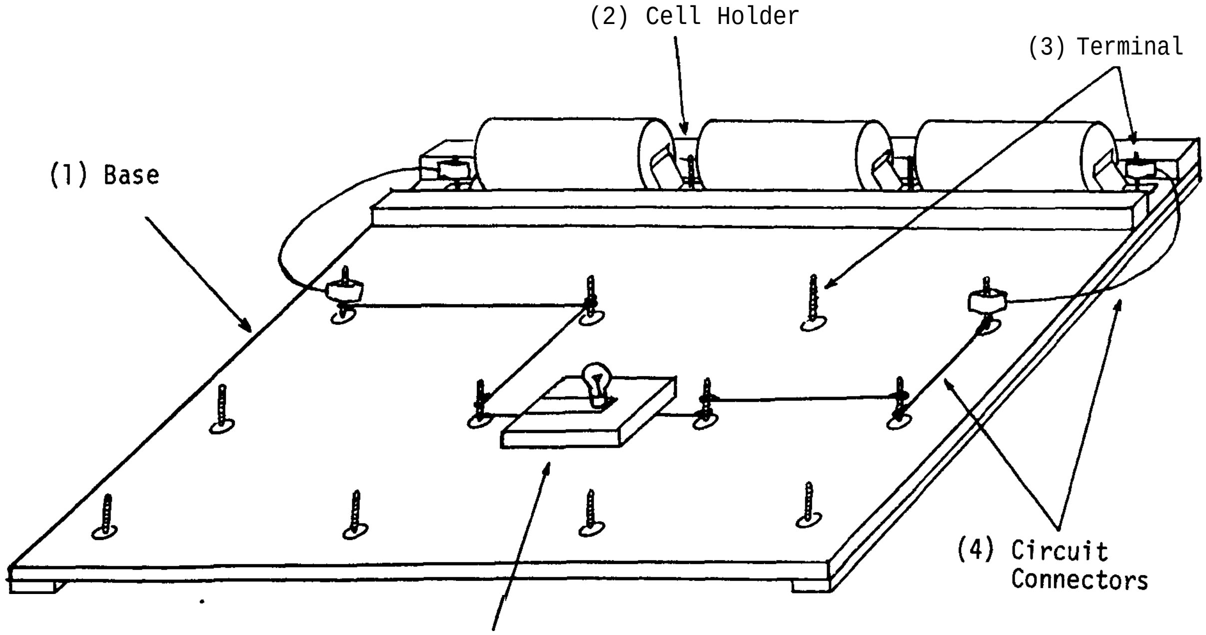




Side View

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

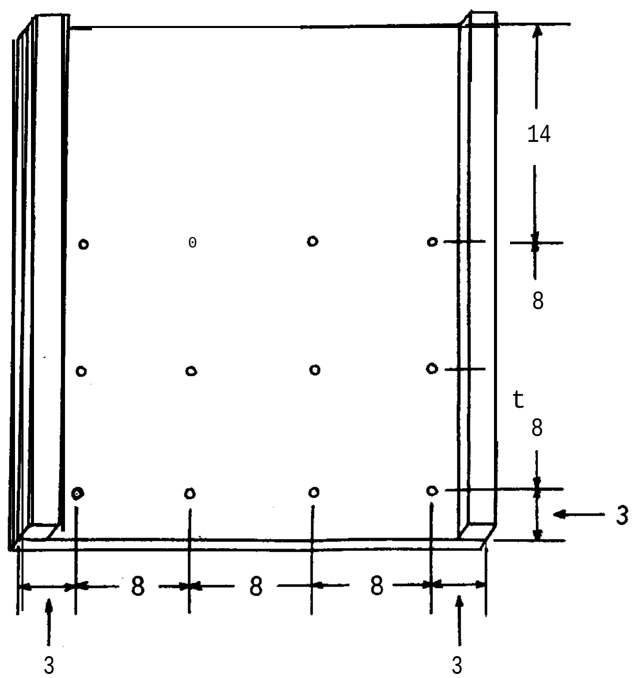
	5	Copper Wires (O)	#18, 25 cm long
(5) Bulb Holders	3	Wood (P)	5 cm x 3 cm x 2 cm
	3	Coat Hanger Wires (Q)	6 cm long
	3	Eye Screws (R)	Approximately 3 cm long
	6	Screws (S)	1 cm long, approximately
	3	Washers (T)	--
	3	Metal Sheets (U)	3 cm x 2 cm x 0.02 cm
	--	Assorted Flashlight Bulbs (V)	--

b. Construction

(1) Base

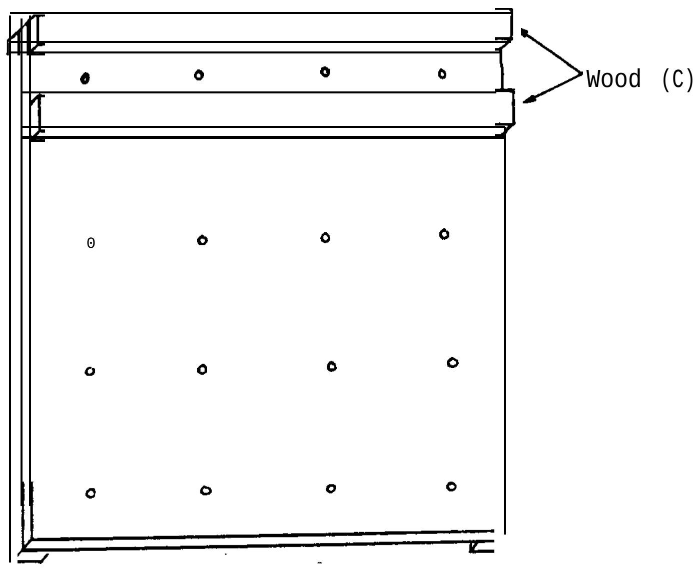
Drill 12 holes (diameter 0.3 cm) through the plywood (A) in the positions indicated. If a piece of scrap wood is placed beneath the plywood during drilling the bottom edges of the hole will not splinter so readily.

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.



Botton View

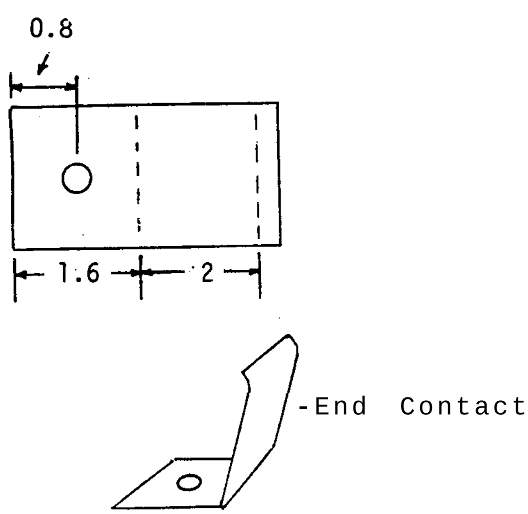
(2) Cell Holder

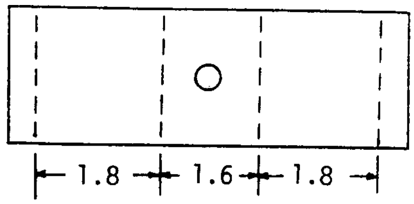


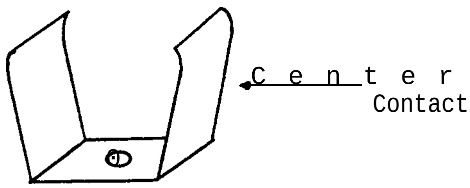
Use two pieces of wood (C) to serve as the cell holder strips. Using nails and glue attach one strip to the end of the base which has not yet been drilled with holes. Place the second strip parallel to, and about 3 cm away from, the first strip. Adjust the separation between the two strips so that they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

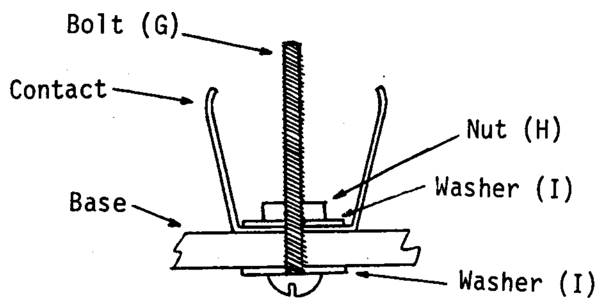
The two strips of flexible metal (E) may be cut from a tin can (or similar source). Drill a hole (0.3 cm diameter) in the end of each sheet, and then bend the sheet into the shape of an end contact, as indicated. Use sandpaper to remove any coating which might interfere with good electrical contact.





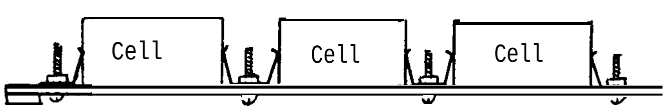


Two more metal strips (F) may be cut from the same source as before. Drill a hole (0.3 cm diameter) at the mid-point of each strip, and then bend each, as indicated, into the shape of a center contact. Use sand-paper to remove any coating which might interfere with good electrical contact.



Side View
(Cross-section)

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.

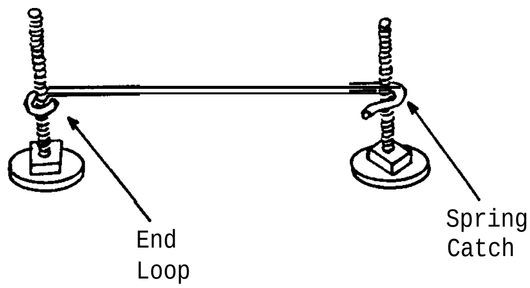


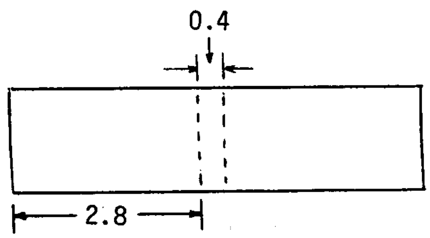
Side View

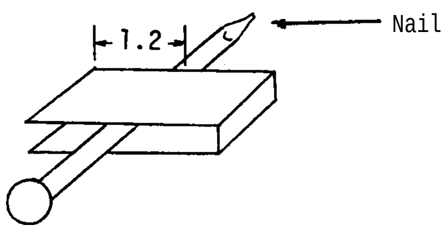
(3) Terminals

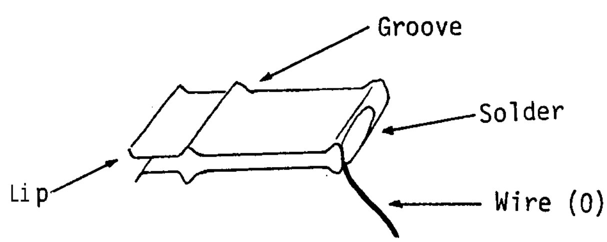
Fit 12 terminals in the remaining holes in the base. Each terminal is made in the same way as described above, each consisting of a bolt (J), a nut (K) and two washers (L).

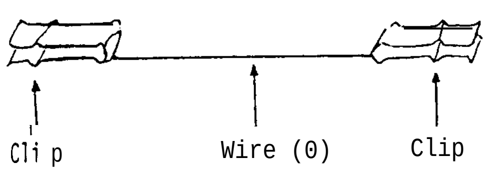
(4) Circuit Connectors







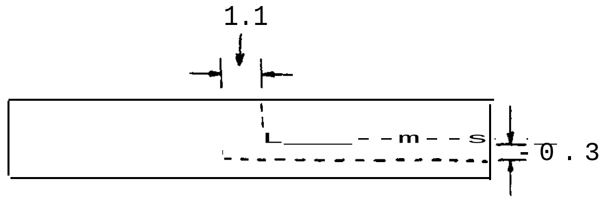




Remove any paint or coating from the wires (M) with sandpaper. Bend one end of each wire into a loop, and slip this onto one of the terminals. Bend the free end of the wire around an adjacent terminal so as to form a spring catch. Make a small lip on the end of the catch, thus permitting the catch to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

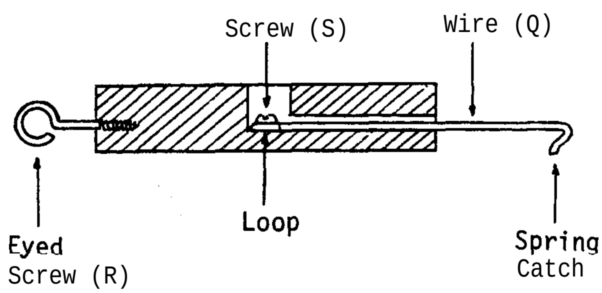
The ten strips of metal (N) may be cut from a tin can or similar source (brass sheet, etc.). Clean the surfaces with sandpaper. Bend each sheet into a "U" shape in which the sides are 0.4 cm apart. Then place a nail (0.2 cm diameter) between the sides of the "U" sheet, and squeeze the sheet on either 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

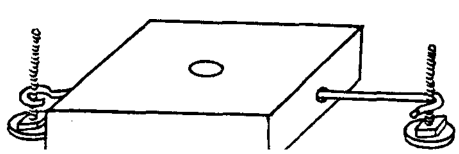
Drill a vertical hole (1.0 cm diameter, 1cm deep) into the middle of the top surface of the wood (P). Drill a horizontal hole (0.3 cm diameter) into the middle of one end of the block, so as to meet the first hole.

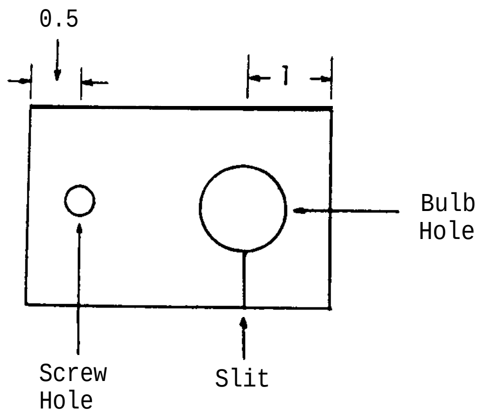


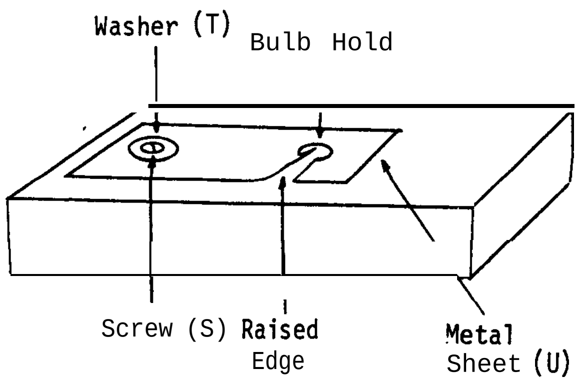
Cross Section

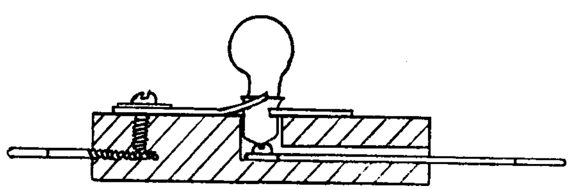
Clean the surface of the wire (Q) with sandpaper. Insert one end of the wire fully into the horizontal hole, and using a pair of dog-nosed pliers (inserted through the vertical hole) bend a loop into the inserted end of the wire. Insert a small screw (S) through the loop to attach the wire **permanently**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

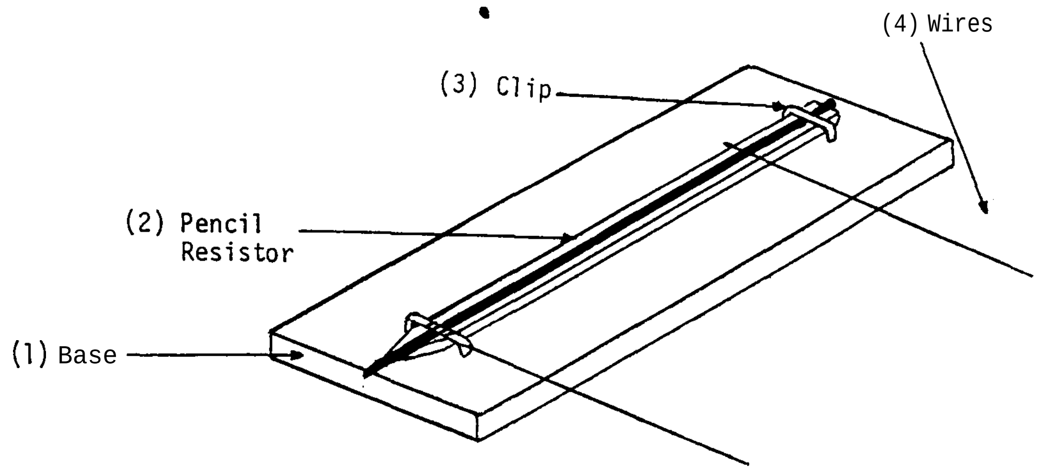
Three identical bulb holders should be made, each with a selection of bulbs (V) (e.g., 1.1 volts, 2.5 volts, 6.2 volts).

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)



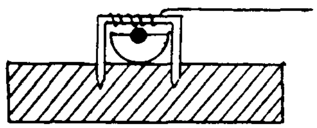
a. Materials Required

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

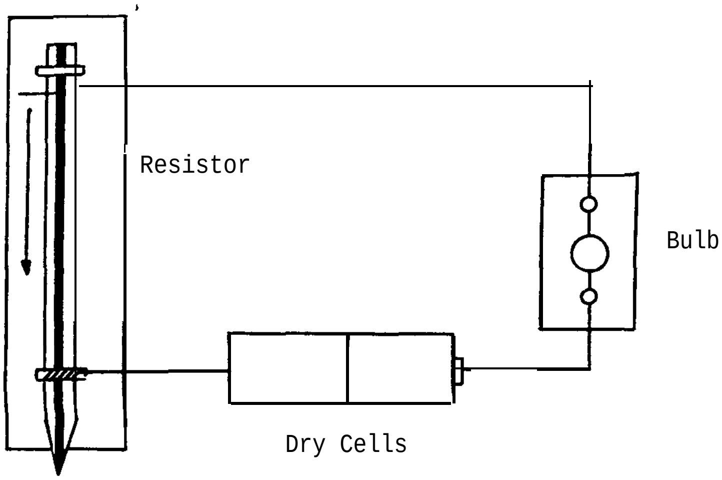


Cross Section

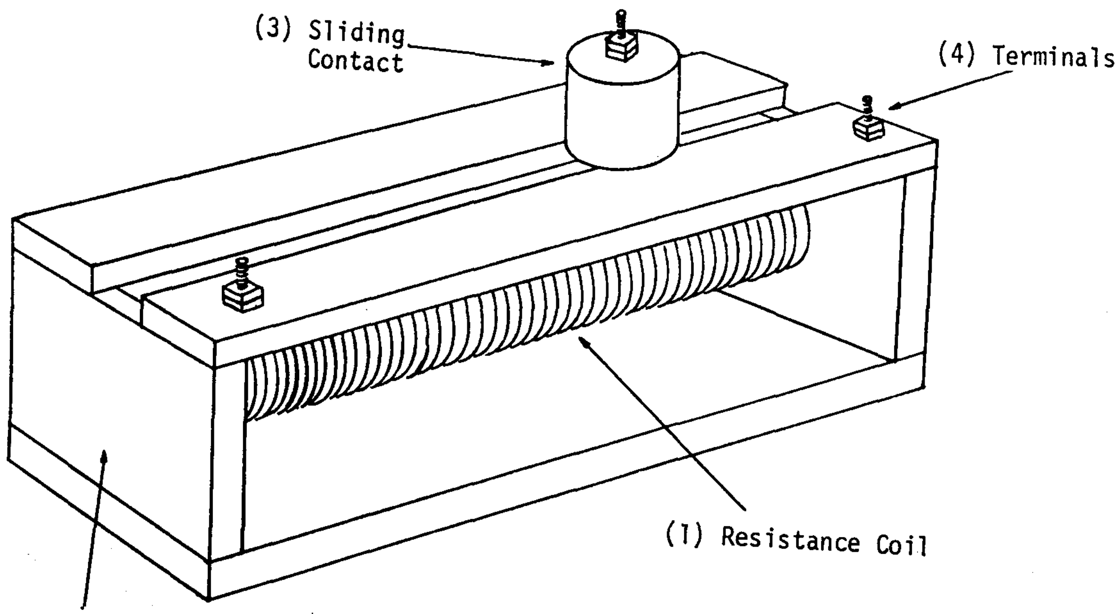
Take the bare end of a length of copper wire (D), and wrap it around the loose clip, so that when the latter is tapped securely into position the copper wire makes good contact with the pencil lead.

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)



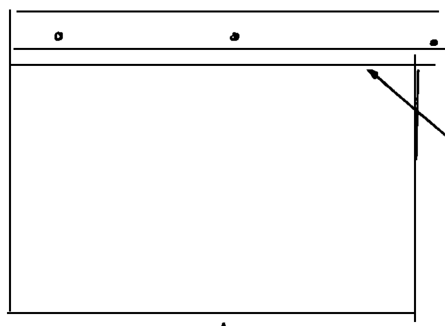
a. Materials Required

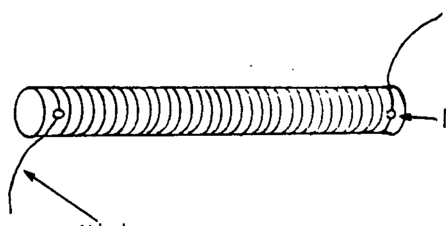
Components	Qu	Items Required	Dimensions
(1) Resistance Coil	1	Wooden Dowel (A)	26 cm long, 2.5 cm diameter
	1	Asbestos Paper (B)	40 cm x 26 cm
	1	Nichrome Wire (C)	#20, 450 cm long
(2) Coil Support	1	Wood (D)	30 cm x 7.5 cm x 2 cm
	2	Wood (E)	8 cm x 7.5 cm x 2 cm
	2	Plywood (F)	30 cm x 3 cm x 0.7 cm
(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





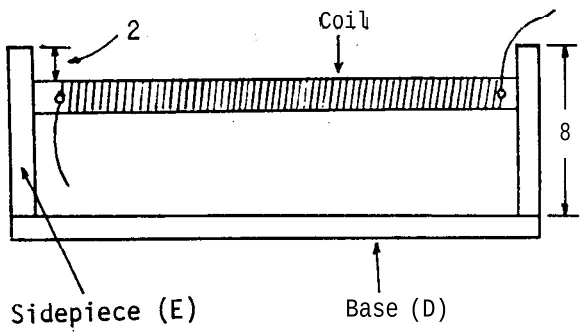
The dimensions of the apparatus depend very much on the resistance required. In this case a 25 ohm resistor, capable of carrying a current of up to 3 amps was required, and it was decided that this could be achieved by using some 400 cm of #20 nichrome wire which had a resistance of approximately 1 ohm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

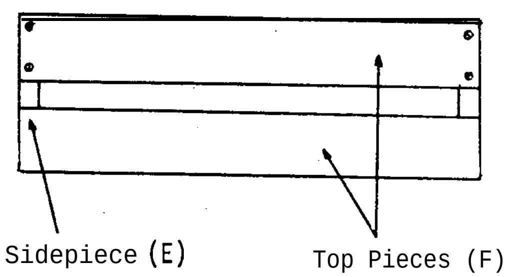
(2) Coil Support

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.



Side View

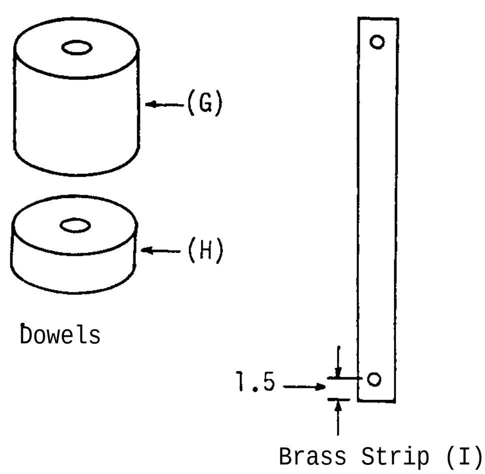
Set the two pieces of ply-wood (F) in position on top of the support as indicated, but only screw one piece in position for the moment.

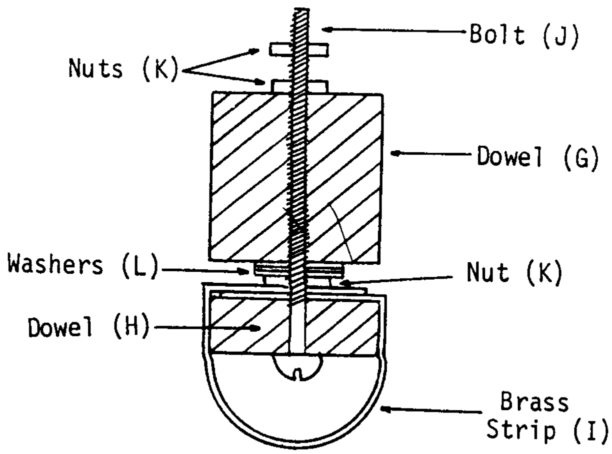


Top View

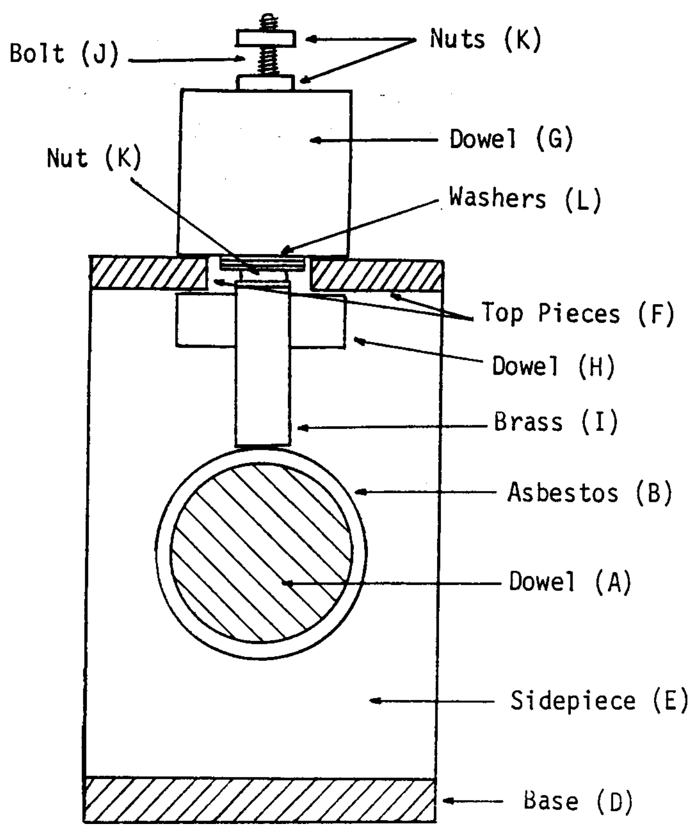
(3) Sliding Contact

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)

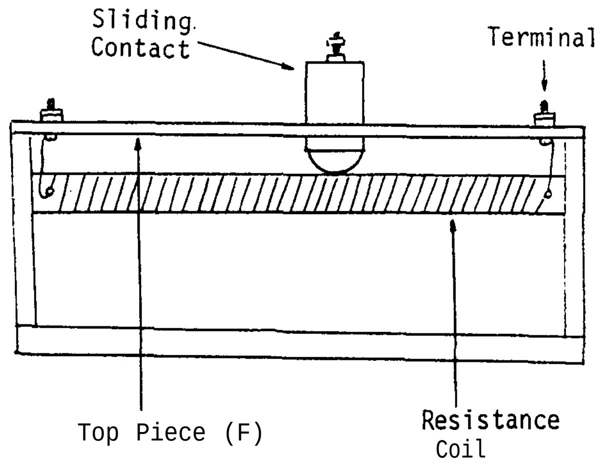


End View
(Cross-section)

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



Side View

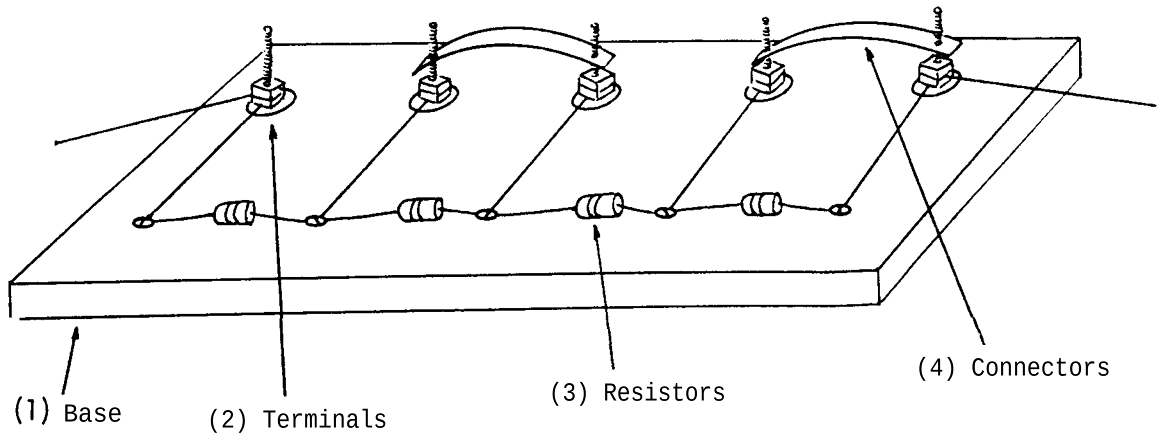
Use the nuts (N) and bolts (M) to make two terminals [see VIII/AZ, Component (4)], one at either end of the support top piece, and fasten the free ends of the resistance coil to these terminals.

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



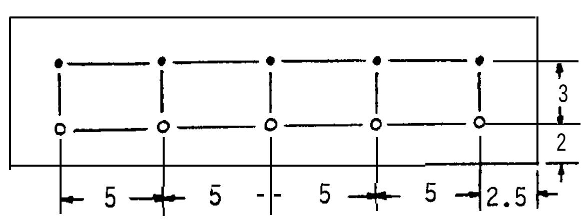
a. Materials Required

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

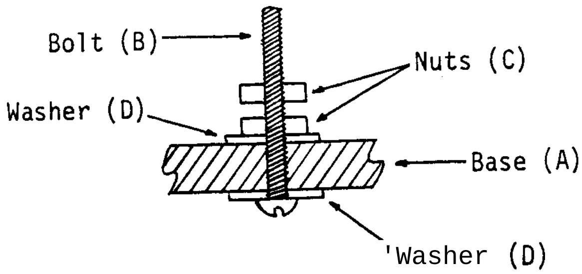
Use wood (A) for the base. Mark on the top surface the position of the terminals and screws as indicated.



• Terminal Positions

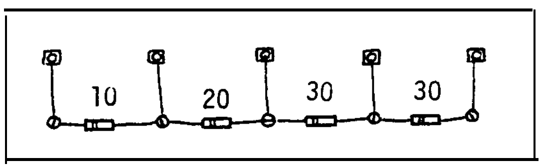
0 Screw Positions

(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.

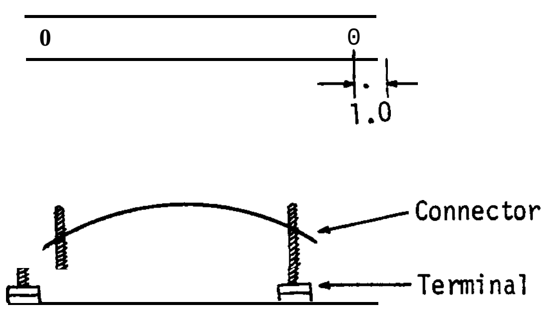
(3) Resistors



Top View

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).

(4) Connectors

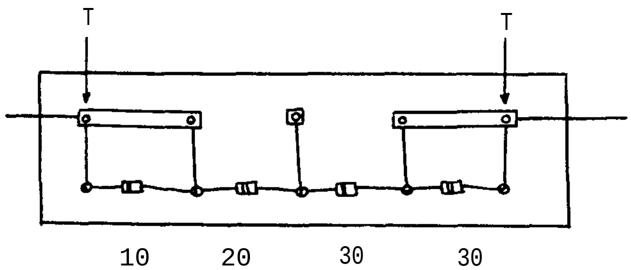


Side View

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.

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.

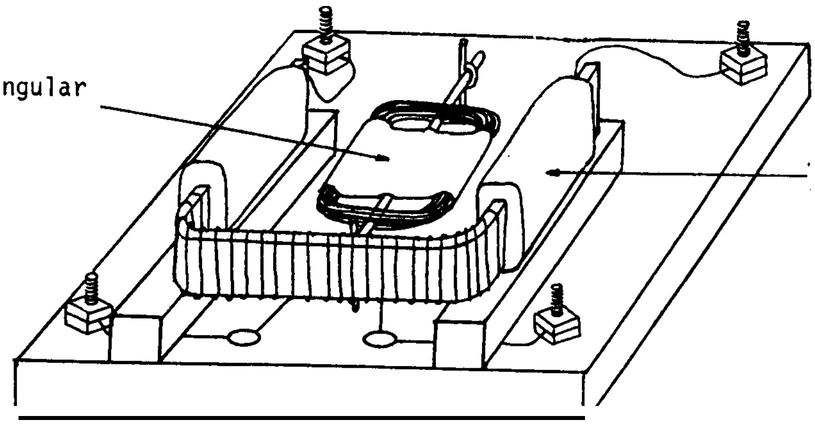
R Ohms	V Volts	I Amps	W Watts
10	5	0.50	2.50
20	5	0.25	1.25
30	5	0.17	0.83

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

D1. Simple Motor

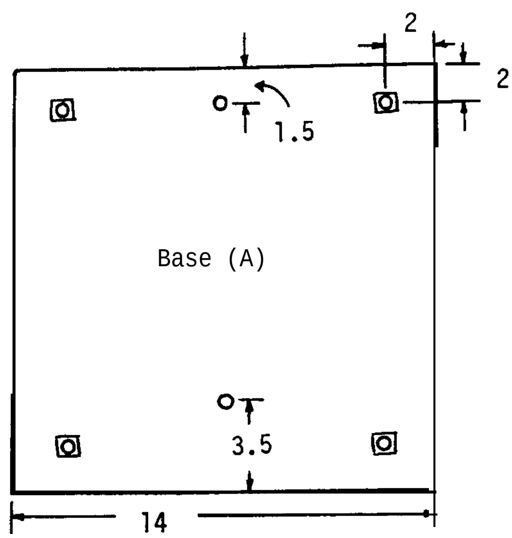


a. Materials Required

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

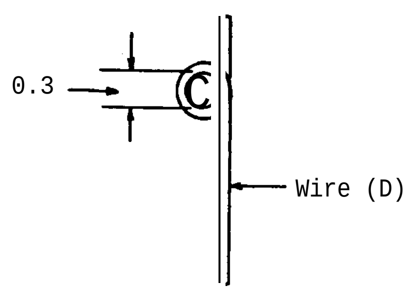
b. Construction

(1) Base



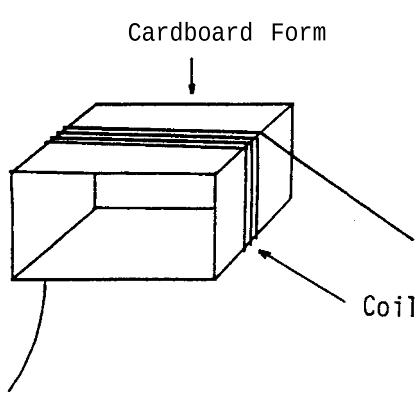
Top View

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.

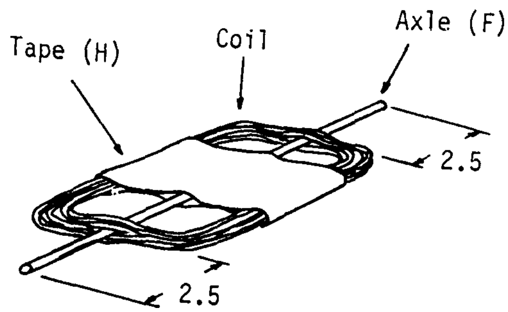


Make two vertical supports for the coil by twisting the coat hanger wire (D) into the shape indicated. Set the supports vertically upright in the newly drilled holes in the base.

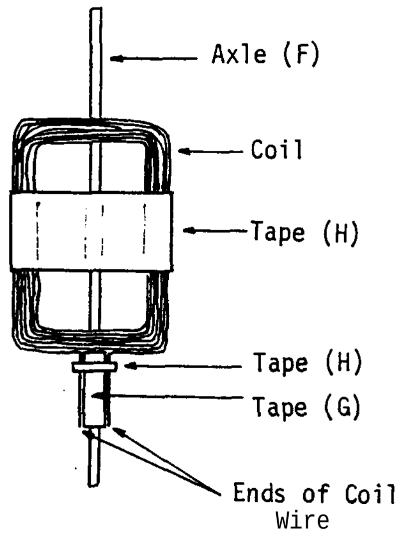
(2) Rectangular Coil



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.

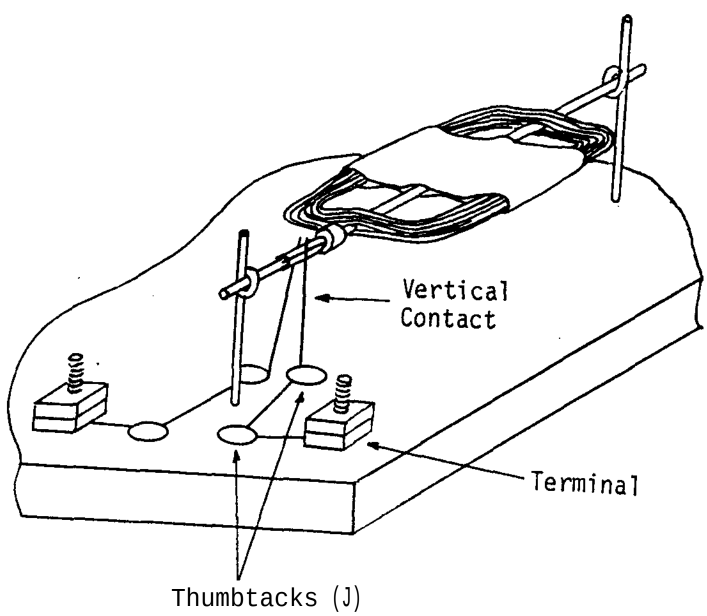


Take the length of straight coat hanger wire (F) and thread it through the middle of the coil to serve as the axle. W r a the masking tape (H) around the coil and axle to hold the coil firmly in position.



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).

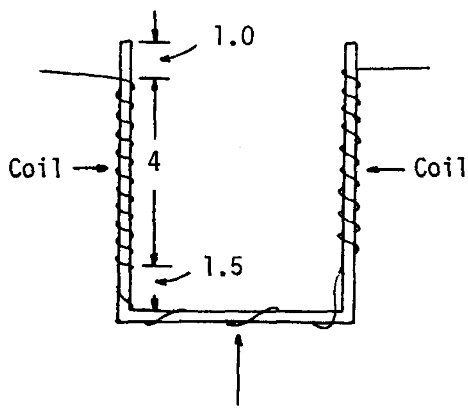
Adjust the ends of the coil wire so that they lie parallel to this insulated portion of the axle, and on either side of it. Cut the parallel wires so that they do not protrude beyond the insulation. Clean the enamel off the wire with sandpaper.



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.



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.

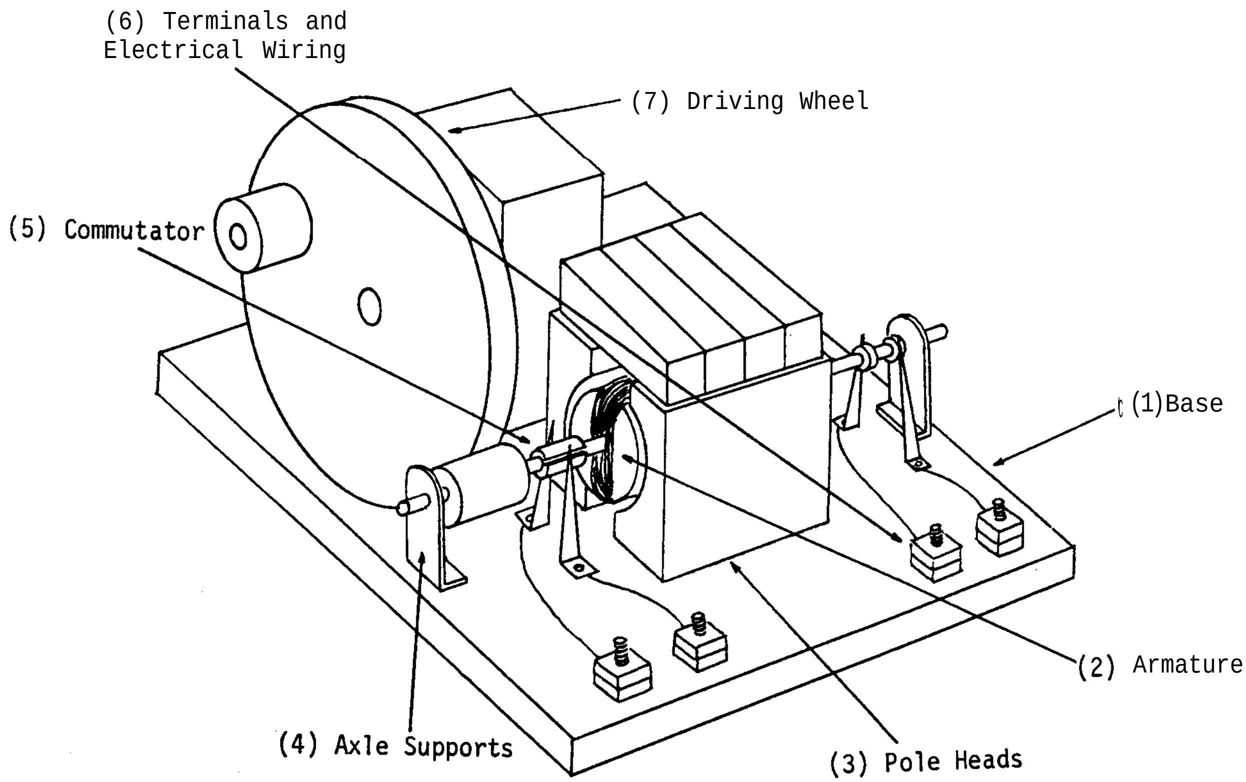
Place two wood strips (N) beneath the electromagnet such that the magnetic poles are either side of, and at the same height as, the middle of the rectangular coil.

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

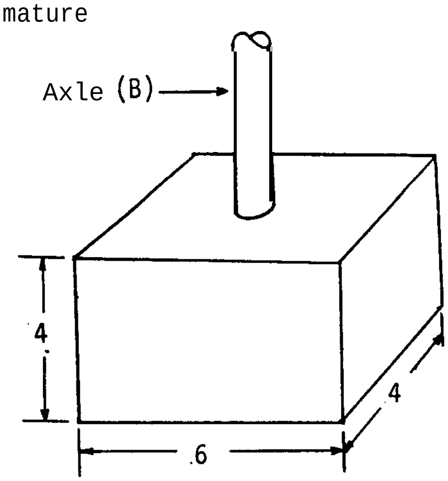
(4) Axle Supports	2	Brass Sheets (I)	5.5 cm x 2.0 cm x 0.2 cm
	1	Masking Tape (J)	--
(5) Commutators	1	Brass Tube (K)	1 cm long, 1 cm external diameter, 0.8 cm internal diameter
	1	Epoxy Resin (L)	--
	2	Brass Sheets (M)	5.0 cm x 1.0 cm x 0.1 cm
	1	Brass Tube (N)	1 cm long, 1 cm external diameter, 0.8 cm internal diameter
	2	Brass Sheets (0)	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

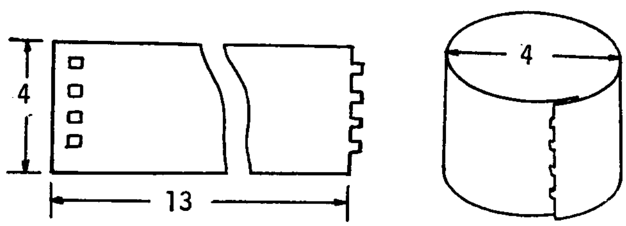
(1) Base

Use the wood (A) as the base.

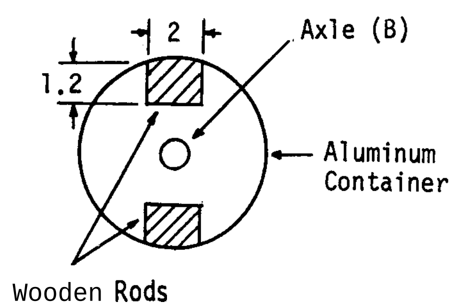
(2) Armature



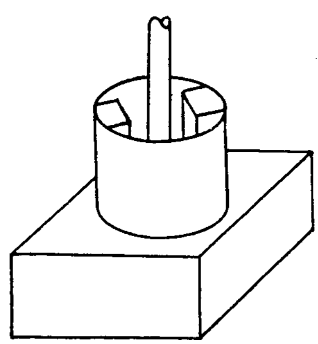
Take a wooden block, and drill a vertical hole (0.8 cm diameter) through its center so that it can support steel axle (B). The latter may be a very long nail with the head removed.



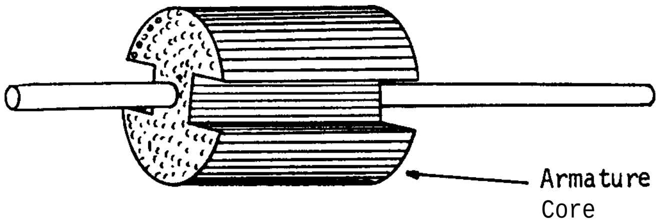
Take a sheet of aluminum (13 cm x 4 cm) and with the help of an appropriate series of end projections and holes make it into a cylindrical container (4 cm tall, 4 cm diameter).



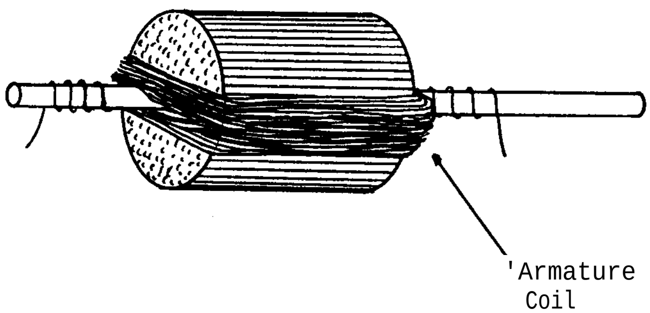
Top View



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.

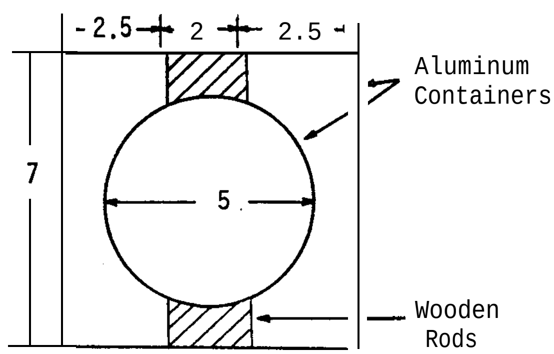


Cover the ends of the nails (not the wood) at both ends of the container with epoxy resin (D), so that when it dries the nails are welded together into a solid soft iron core, penetrated along its axis by the steel axle (B) protruding 4 cm at one end and 7 cm at the other. Remove the aluminum container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



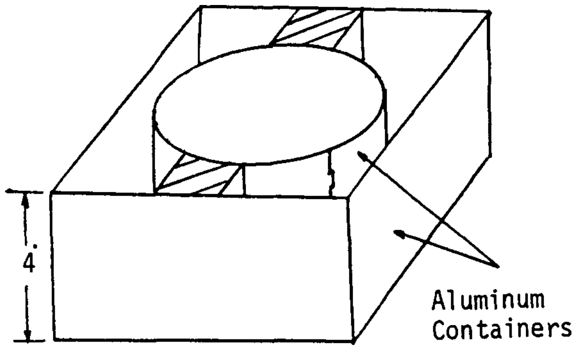
Wind as much magnet wire (E) as possible into a coil around the core, making sure that you have about 10 cm of both ends left free on completion of the coil. Temporarily twist the loose ends around the long end of the axle. The resistance of the coil will be approximately 5 ohms.

(3) Pole Heads

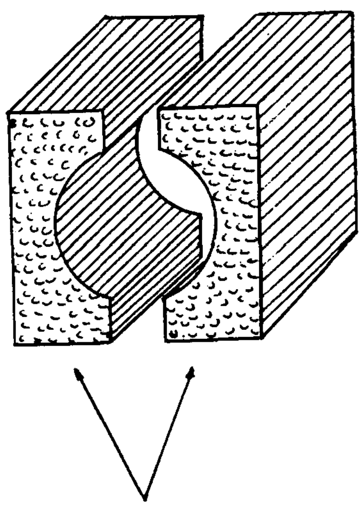


Top View

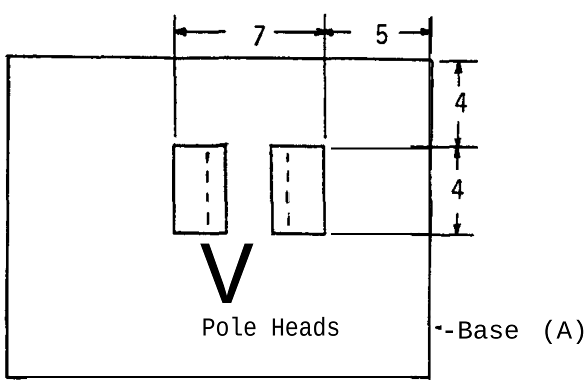
The pole heads are made in very much the same way as the armature core. Two open ended aluminum containers are required this time, one cylindrical (5 cm diameter, 4 cm long) and one a rectangular cube (7 cm x 7 cm x 4 cm). The cylindrical one is placed inside the rectangular one, and the two held apart 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

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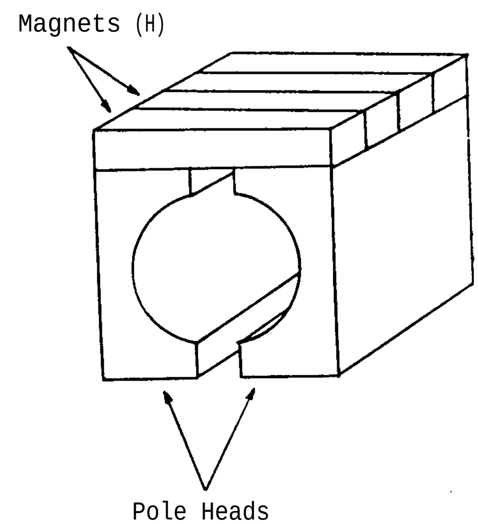
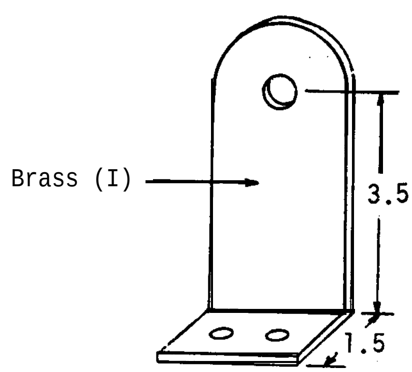


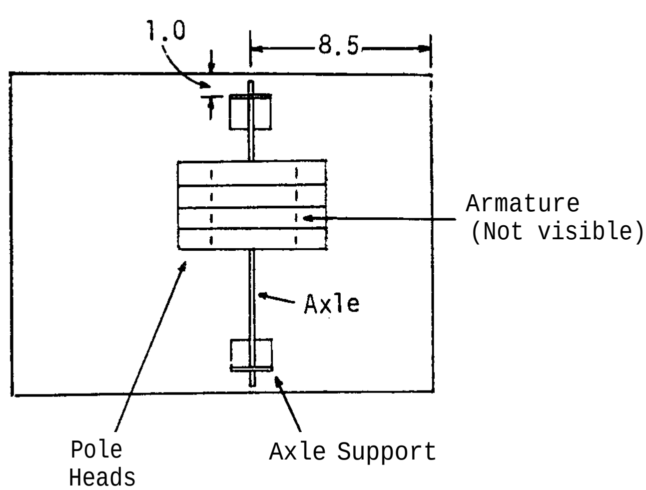
the pole heads. The magnet may be purchased, or made (as described under IX/Alfrom the steel bars (H).

(4) Axle Supporters

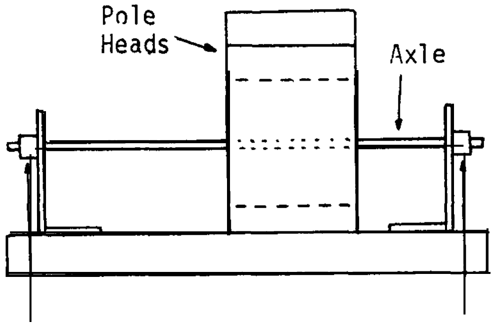


Make two axle supports out of the two brass sheets (I), drilling one hole (0.8 cm diameter) in the upright portion to take the axle, and two holes (0.3 cm diameter) in the base portion to take two screws.

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.



Top View



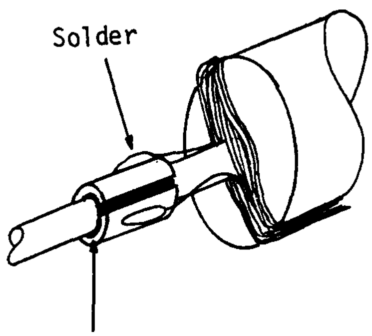
Side View

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,

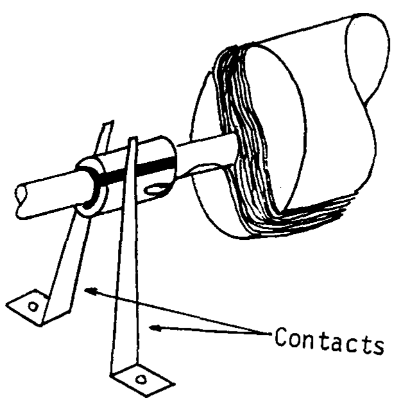
(5) Commutators

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

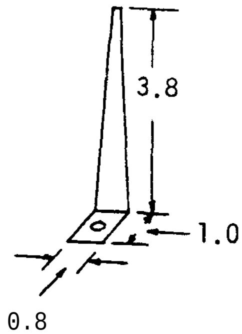
Take some epoxy resin (L), which is a good insulator, and coat all the inner surfaces of the two halves with resin about 0.1 cm thick.



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.

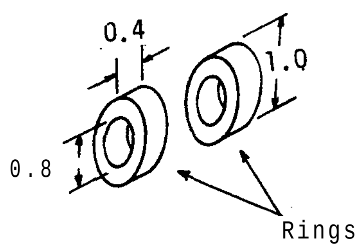


Take the two loose wires from the armature coil and, after cleaning the ends with sandpaper, solder one to one split half and the other to the other split half.

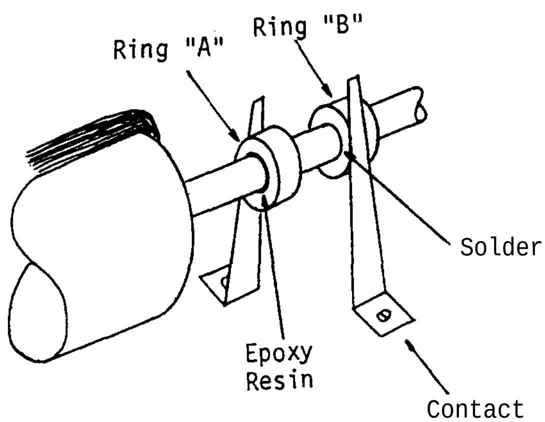


Cut two identical contacts out of the thin brass sheets (M) as shown. Attach these to the base of the apparatus with screws, so that they are in spring contact with opposite sides of the split halves.

The DC commutator is now complete.

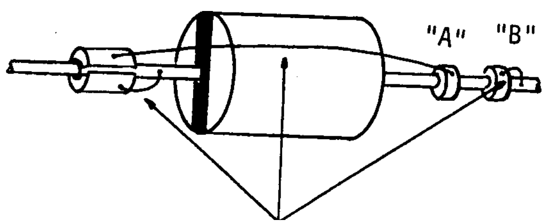


To make the AC commutator, cut two identical rings from the brass tubing (N).



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.



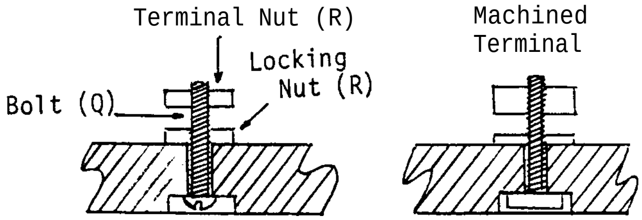
Electrical Connections

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.

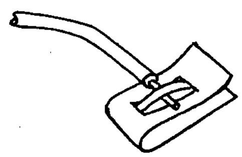
Connect ring "A" electrically to the other split half by soldering a length of magnet wire (P) from one to the other.

The AC commutator is now complete,

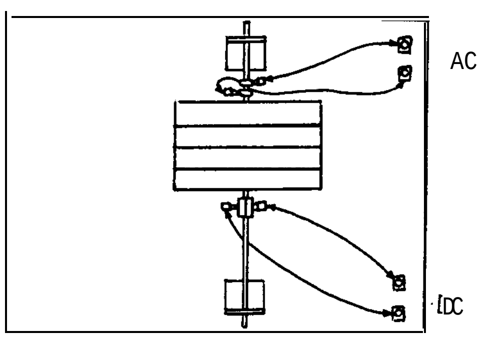
(6) Terminals and Electric Wiring



Side View
(Cross-section)



Fahnstock Clip



Top view

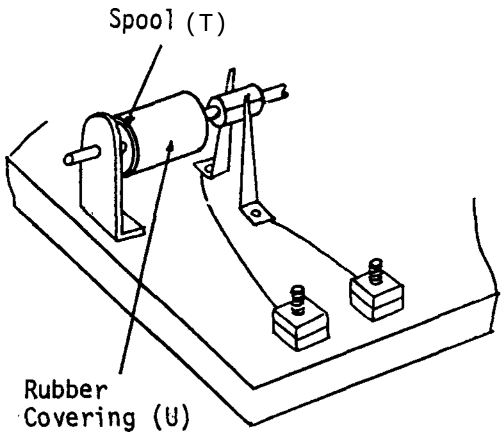
Drill four holes through the base to take four terminals, two to serve as an AC outlet and two as a DC outlet.

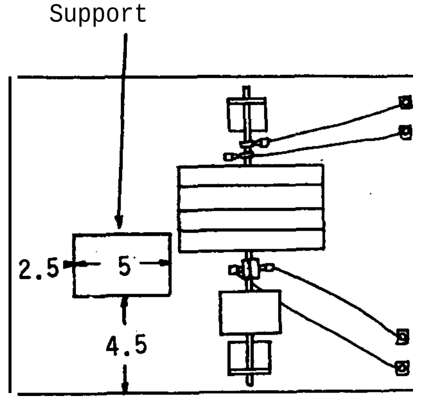
Make each terminal as described under VIII/A2, Component (4). Each terminal requires a bolt (Q), and two nuts (R).

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.

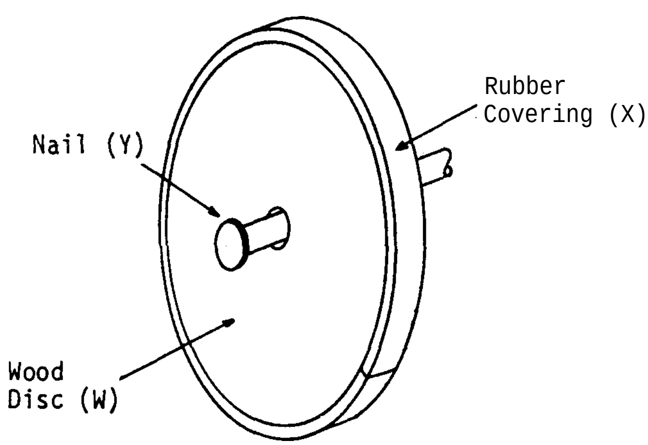
(7) Driving Wheel System



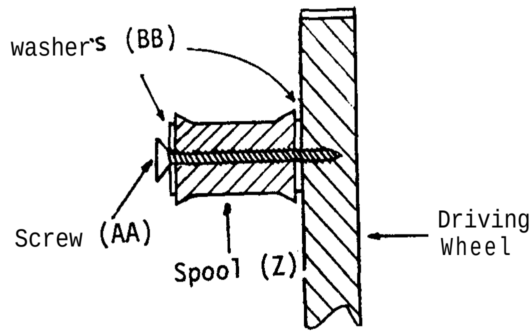


Top View

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.



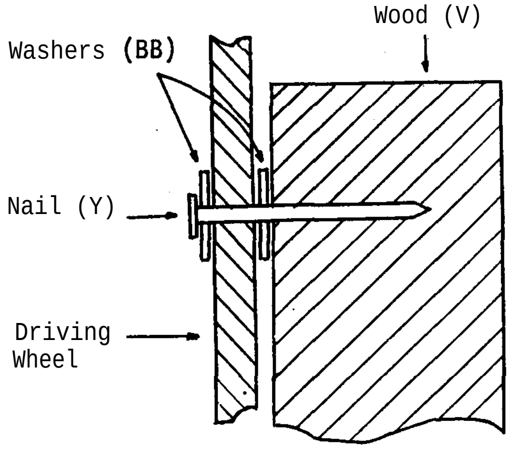
Use the wooden disc (W) to serve as the driving wheel. The rubber strip (X), cut from an old car inner tube, should be nailed around the perimeter of the disc. Drill a hole (0.8 cm diameter) through the center of the disc, and pass a nail (Y) through it to serve as a pivot.



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.

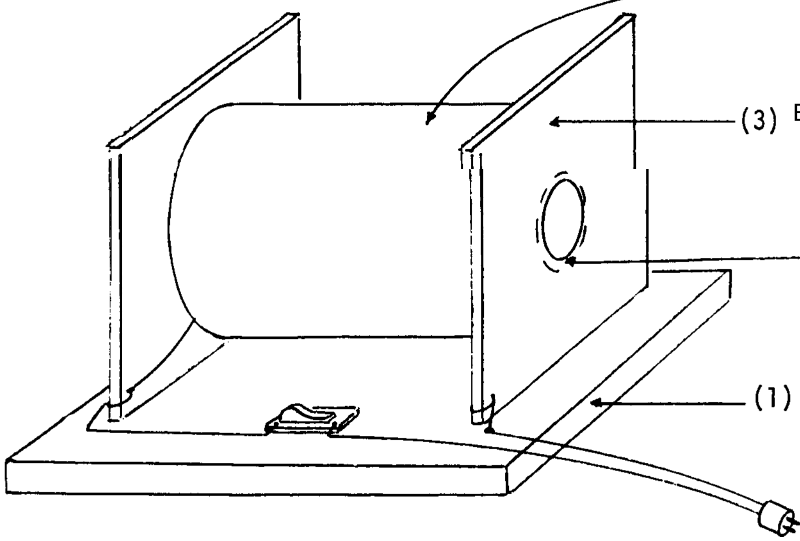
IX. ELECTROMAGNETISM APPARATUS

A. ELECTROMAGNETISM APPARATUS

The apparatus in this group is primarily concerned with the creation of magnetic fields in various forms.

A. ELECTROMAGNETISM APPARATUS

Al, Magnetizing Coil and Magnets ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	15 cm x 15 cm x 2 cm
(2) Spool	1	Wooden Dowel (B)	3 cm diameter, 8 cm long
(3) Endpieces	2	Wooden Strips (C)	8 cm x 8 cm x 0.5 cm
(4) Coil	1	Roll of Magnet Wire (D)	#22, 1 kg
	1	Switch (E)	220 volts
	1	Double Electrical Cord (F)	#20, 200 cm long
	1	Two Pin Plug	220 volts
	1	Insulating Tape (H)	--

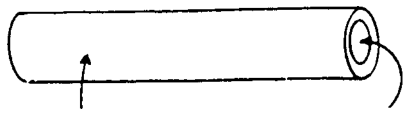
© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 138-142.

b. Construction

(1) Base

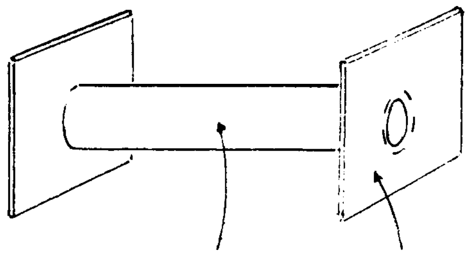
Use wood (A) as the base.

(2) Spool



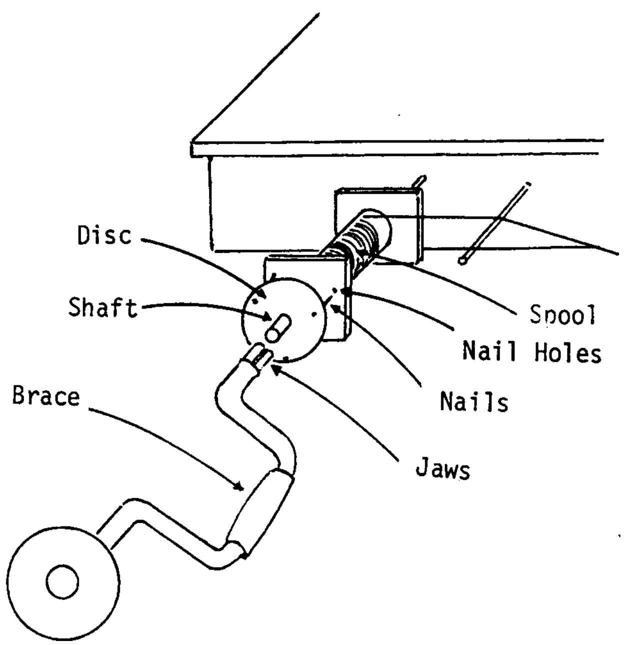
Drill a hole (2 cm diameter) along the axis of the wooden dowel (B) to make an appropriate spool.

(3) Endpieces



Drill a hole (2 cm diameter) in the middle of each wood strip (C) and attach the strips to either end of the spool with wood cement.

(4) Coil

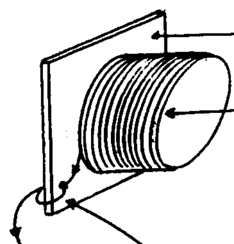


Wind all of magnet wire (D) on to the spool taking care to leave about 25 cm of free wire at either end of the coil for appropriate connections. The winding of the coil may be facilitated by the use of a brace as follows.

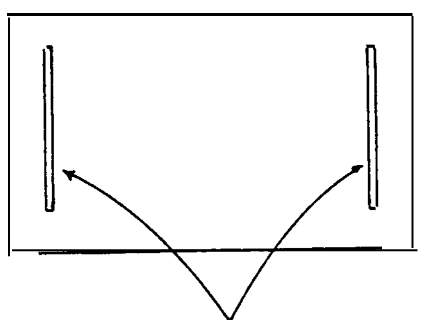
Hammer two large nails (15 cm long) into the side of a bench so that they protrude horizontally some 50 cm apart. Place the spool to be wound on one of the nails. Fasten the first turn of magnet wire around the spool in such a way that it will not slip on turning the spool. Then get your partner to hold the wire taut over the second nail so that it may be wound under tension.

Attach a short shaft (2 cm long, 1 cm diameter) to the center of a circular disc (7 cm diameter, 0.5 cm thick) by means of a screw. Hamner three nails through the perimeter of the disc and drill three corresponding holes in the endpiece of the spool to take the protruding nails. Clamp the jaws of the brace firmly on to the shaft. Lock the disc and spool together by means of the disc nails, and then begin to wind the coil by turning the brace.

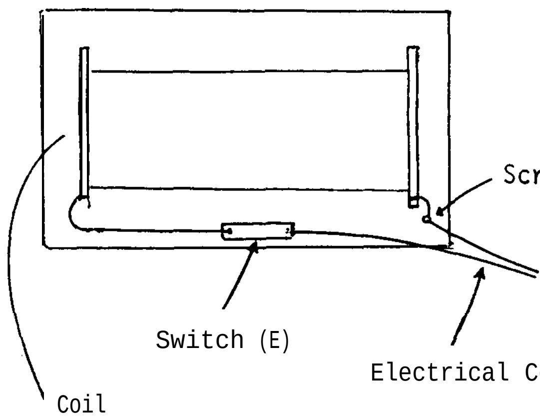
Drill a small hole in each endpiece and loop the wire ends through these holes to prevent unwinding of the coil.



Make two insets (8 cm long, 0.5 cm wide, 0.2 cm deep) in appropriate positions on the base to hold the endpieces. Fix the endpieces firmly in the insets with wood cement.



Attach switch (E) to the base, and connect one of the loose wires from the coil to the switch. Insert a screw into the base as indicated, and attach the other wire from the coil.to the newly inserted screw. Take



the double electrical cord (F) with two pin plug (G) attached, and connect one wire to the screw, and the other wire to the switch.

Since the coil and wires will carry a high voltage (220 volts), it is important that all wiring should be covered with insulating tape (H). Cover the coil, the wire and the screw with the tape.

C. Notes

(i) To magnetize an item, place a suitable steel specimen in the center of the coil. Switch the current quickly on and off. The specimen will be magnetized on removal from the coil.

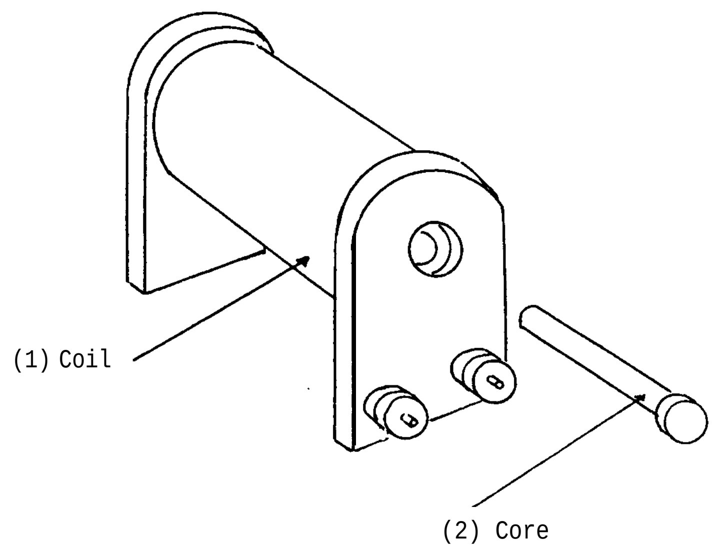
Ticonal is an ideal alloy for making magnets, but is rarely available on local markets. High quality tool steel is a good second best, and is generally found in good quality tools (chisels, screwdrivers, drill bits, etc.), as well as domestic items such as razor blades and sewing needles.

Unfortunately, the "high grade steel' sold on many local markets tends to to be of poor quality, and does not retain magnetism well. However, if the steel is heated to red heat in any oxy-actylene flame, and then quenched in cold water, it tends to be hardened, and hold magnetism somewhat better. (It should be noted that "steel rods" used in construction work for reinforcing concrete are made of soft iron, and cannot be permanently magnetized.

This magnetizing coil is designed for use with a 220 volt mains supply, and is capable of producing extremely strong magnets, It would also work with a 110 volt supply, but the magnetism induced in a given specimen would be weaker than with a 220 volt supply. The magnetizing coil should never be switched on and left on, as it would overheat and burn out. It is designed for usage over very short periods of time (2 or 3 seconds only).

To demagnetize a specimen, place the magnet inside the coil and hold its end very firmly. Switch on the current, and remove the specimen from the coil maintaining a firm grip on it. The current is not switched off until the specimen is completely out of the coil.

A2. Multipurpose Coil with Cores



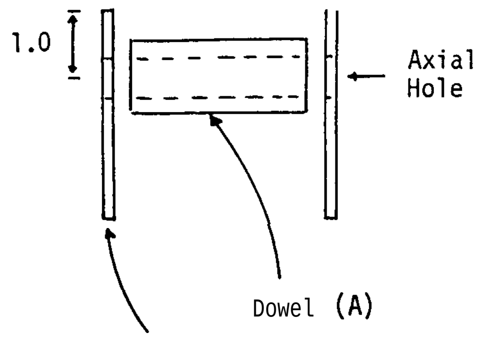
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Coil	1	Dowel (A)	1.2 cm diameter, 3 cm long
	2	Wood Strips (B)	3 cm x 2 cm x 0.5 an
	1	Roll of Magnet Wire (C)	#22
	1	Masking Tape (D)	--
	2	Brass Bolts (E)	0.3 cm diameter, 1.5 cm long
	4	Nuts (F)	0.3 cm internal diameter
(2)Core	1	Bolt (G)	0.4 cm diameter, 4.5 cm long
	1	Soft Iron Plate (H)	3 cm x 2 cm x 0.3 cm

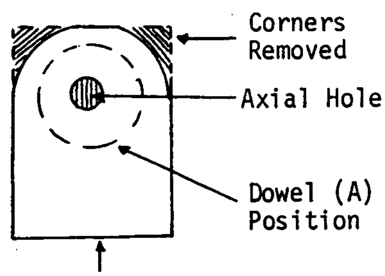
b, Construction

(1) Coil

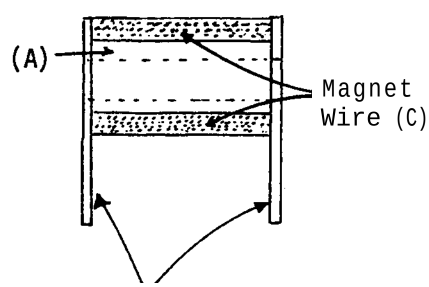
The size of the coil is not critical, but it does affect the spacing and size of components used on the Magnetic Field Apparatus (IX/A4) and Moving Coil Galvanometer (X/C2).



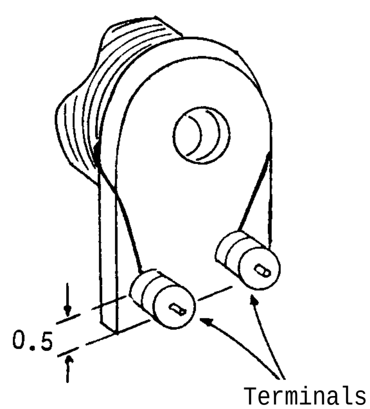
Drill a hole (0.6 cm diameter) along the axis of the dowel(A).



Drill similar holes in the two wood strips (B), at a distance of 1.0 cm from the ends, so that when the strips are attached to either end of the wooden dowel (A) they serve as endpieces with a common axial hole. cut off the top corners of the end-pieces, and smooth them down with sandpaper.



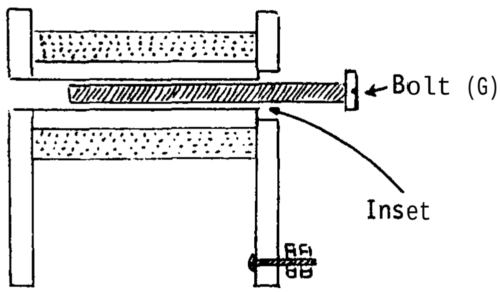
Wind ten layers of magnet wire (C) on to the dowel, leaving about 10 cm of wire free at either end of the coil. Cover the final layer of wire with masking tape (D) to hold the coil in position.



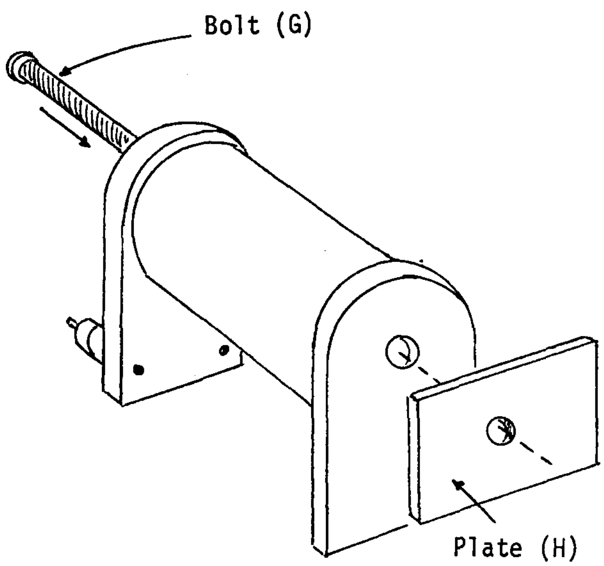
Use bolts (E) and nuts (F) to make two terminals as described under VIII/A2, Component (4), and attach them to one endpiece as indicated.

Clean the ends of the two wires from the coil, and fasten them under the locking nuts of the respective terminals. Make sure that it is possible to see the way in which the wire from each terminal begins to wind around the coil, for this makes it possible to determine the direction of the current around the coil, and hence the direction of the magnetic field produced.

(2) Core



Drill an inset (0.4 cm deep, 1.0 cm diameter) over the hole in the endpiece which contains the terminals. Insert bolt (G) in that the bolthead sits snugly in the inset.

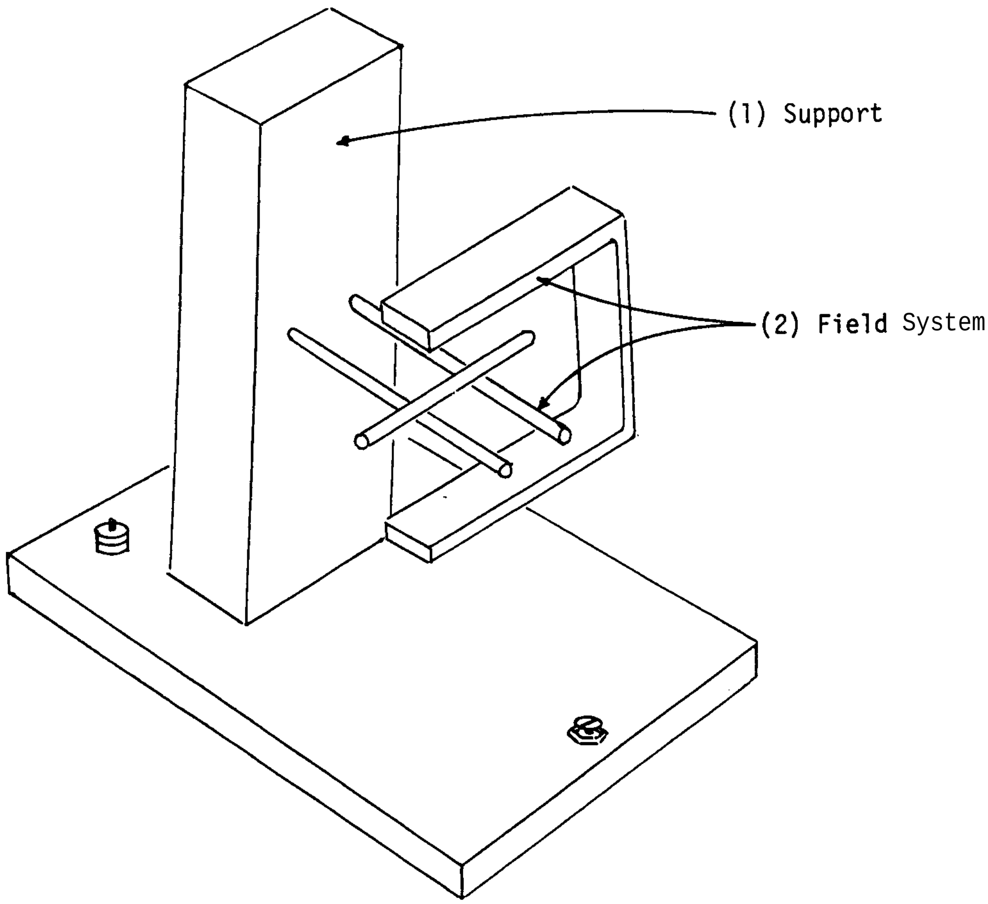


Drill a hole (0.4 cm diameter) through the center of the iron plate (H). Make a thread (0.4 cm diameter) in the hole, and attach the iron plate to the bolt (G) by means of the threaded hole.

C. Notes

(i) The multipurpose coil may be used in a wide range of experiments to produce magnetic fields. It may also be used in instruments [e.g., the Magnetic Field Apparatus (IX/A4) and the Moving Coil Galvanometer (X/C2)] where a fixed magnetic field is required.

A3. Magnetic Field Apparatus ©



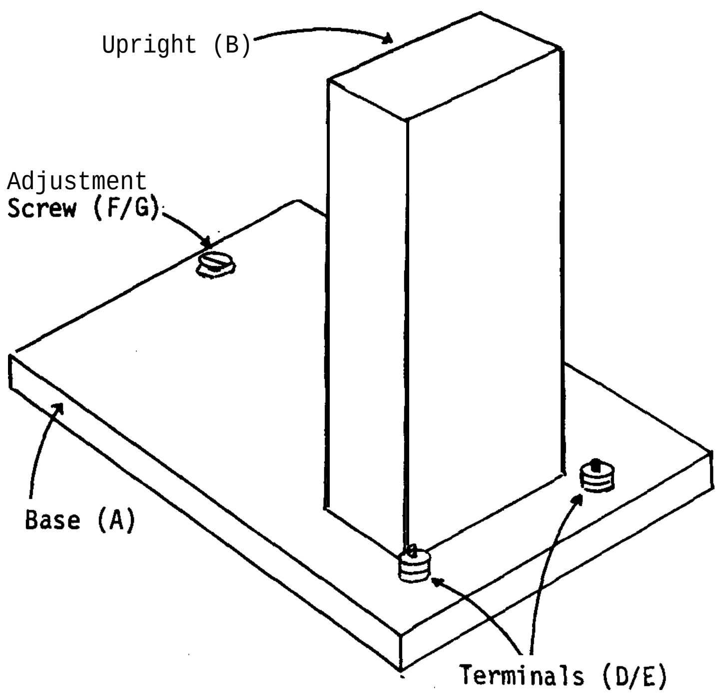
a. Materials Required

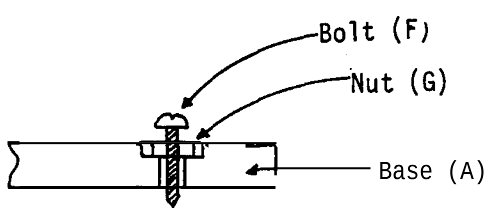
Components	Qu	Items Required	Dimensions
(1) Support	1	Wood (A)	10 cm x 7 cm x 1 cm
	1	Wood (B)	10 cm x 4 cm x 2 cm
	2	Wood Screws (C)	2 cm long
	2	Brass Bolts (D)	0.3 cm diameter, 2 cm long
	4	Nuts (E)	0.3 cm internal diameter
	1	Bolt (F)	0.2 cm diameter, 2 cm long
	1	Nut (G)	0.2 cm internal diameter
	2	Thumbtacks (H)	--

(2) Field System	2	Brass Rods (I)	0.4 cm diameter, 5 cm long
	2	Nuts (J)	0.3 cm internal diameter
	2	Magnet Wires (K)	#22, 8 cm long
	1	Aluminum Rod (L)	0.3 cm diameter, 4 cm long
	1	Horseshoe Magnet (M)	--

b. Construction

(1) Support





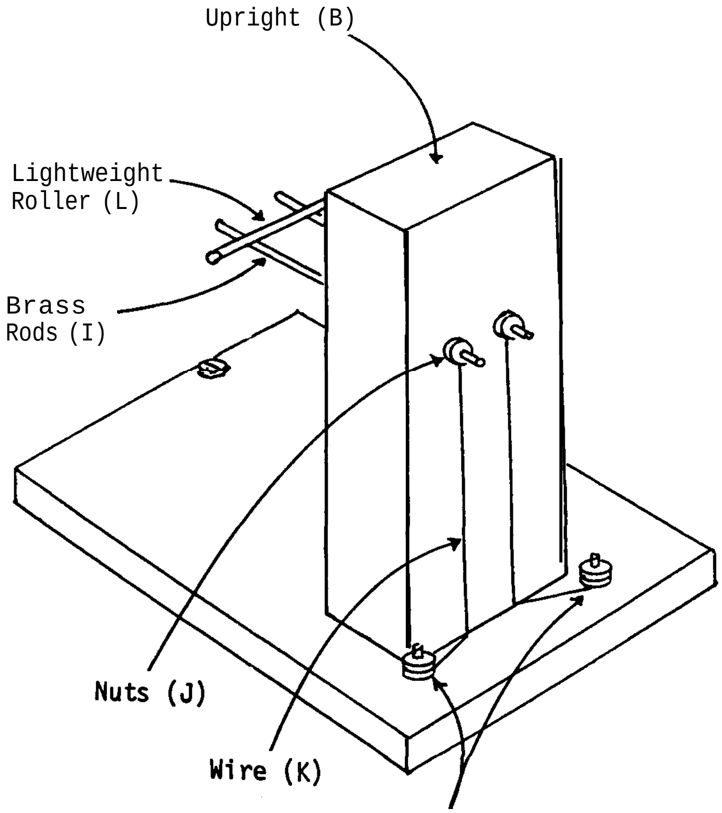
Use wood (A) as the base.

Attach wood (B) vertically to the base with two wood screws (C) passed through the base (4 cm from one end). Use wood cement to insure a firm joint between the upright and base.

Use the bolts (D) and nuts (E) to make two terminals, as described under VIII/A2, Component (4), and attach these to the base (A) just behind the upright (B).

Drill a hole (0.3 cm diameter) through the base to take bolt (F). Inset nut (G) over the hole by striking it into position with a hammer Thread the bolt through the nut thus producing an adjustment screw for levelling the base. At opposite corners on the other side of the base, insert two thumbtacks (H) beneath the base, so that the latter sits on three points, the adjustment screw and two thumbtacks.

(2) Field System



Drill two horizontal holes (0.4 cm diameter) through the upright (B). It is important that the two holes should be at exactly the same height (6 cm) above the base, and that they should be perfectly horizontal.

Take the two brass rods (I), and thread the end of each (thread diameter 0.3 cm). Pass the rods through the newly drilled holes, and use epoxy resin to hold them firmly in position. (Avoid getting the resin on the protruding rod since it is an insulator). Attach nuts (J) to the rod ends, and connect the rods and terminals to one another with magnet wire (K).

Place rod (L) across the horizontal brass rods to serve as a lightweight roller.

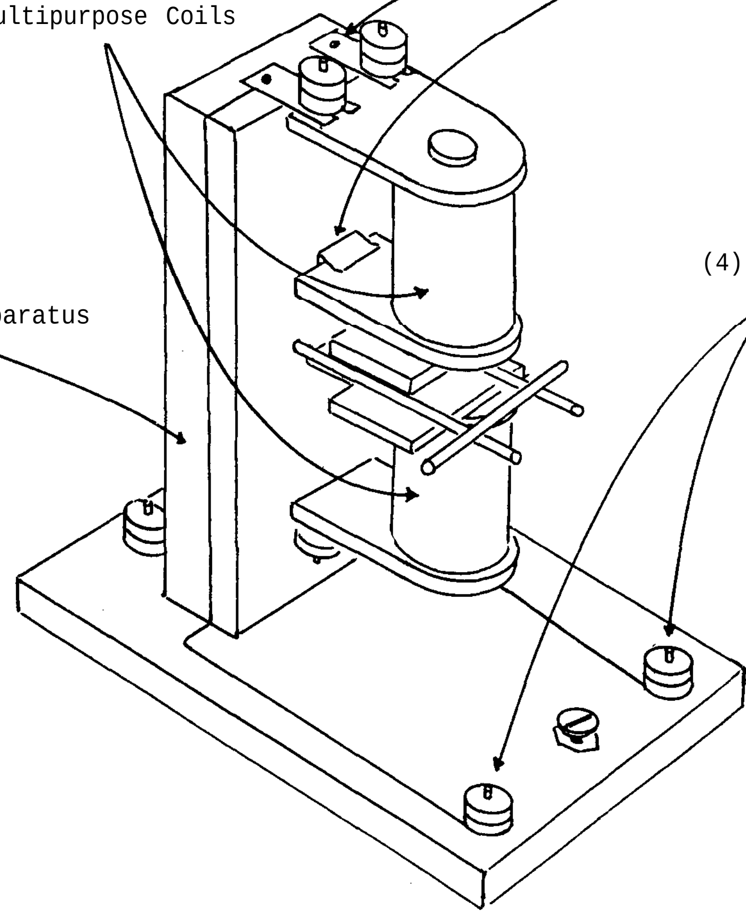
Purchase a strong horseshoe magnet (M) from a local shop. It may be held in position by hand, thus creating a vertical magnetic field at right angles to the lightweight roller.

c. Notes

(i) If three dry cells (1.5 volts each) are connected across the terminals, a current will pass through the lightweight roller at right angles to the magnetic field, and the roller will be propelled along the horizontal rods. This piece of apparatus may be used for studying the force exerted on a current carrying conductor placed in a magnetic field.

(ii) Should there be any difficulty in obtaining a strong horseshoe magnet, then multipurpose coils may be used to replace the magnet. Such a system is described in the next item (IX/A4).

A4. Magnetic Field Apparatus with Multipurpose Coils ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Basic Apparatus	1	Magnetic Field Apparatus (A)	IX/A3, No magnet required
(2) **Multipurpose Coils**	2	Multipurpose Coils with Cores (B)	IX/A2
(3) Coil Holders	2	Brass Sheets (C)	2 cm x 2 cm x 0.02 cm
	4	Screws (D)	Approximately 0.6 cm long
	4	Brass Sheets (E)	3 cm x 0.8 cm x 0.05 cm

	4	Screws (F)	Approximately 0.6 cm long
(4) Terminals	2	Brass Bolts (G)	0.3 cm diameter, 2 cm long
	4	Nuts (H)	0.3 cm internal diameter
	1	Magnet Wire (I)	#24

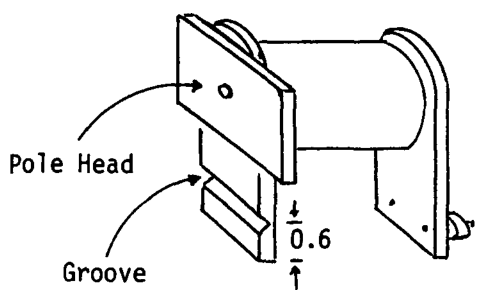
b. Construction

(1) Basic Apparatus

Make the Magnetic Field Apparatus (A) as described under IX/A3. A horseshoe magnet is not required, and the magnetic field is produced by means of the additional components described below.

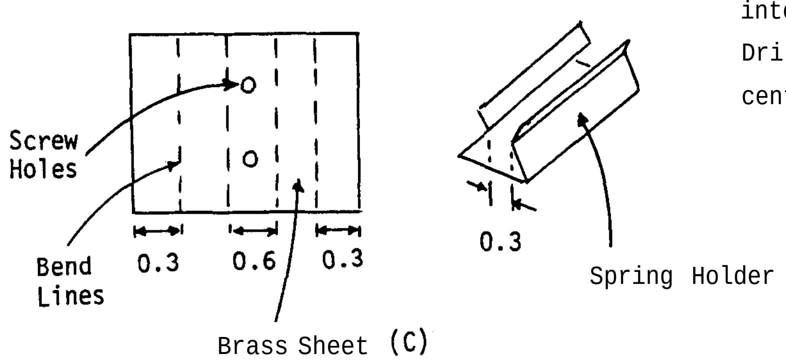
(2) Multipurpose Coils

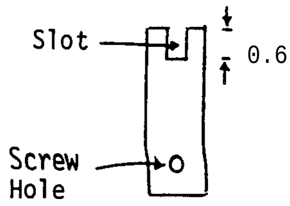
Make two Multipurpose Coils (B), complete with pole heads, as described under IX/A2. Cut a horizontal groove in the front endpiece of each (just beneath the pole heads) to insure a good grip for the coil holders.



(3) Coil Holders

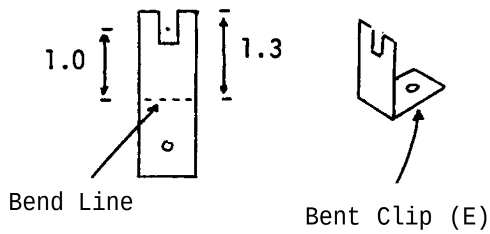
Bend the two brass sheets (C) into spring holders as indicated. Drill two screw holes in the center portion.





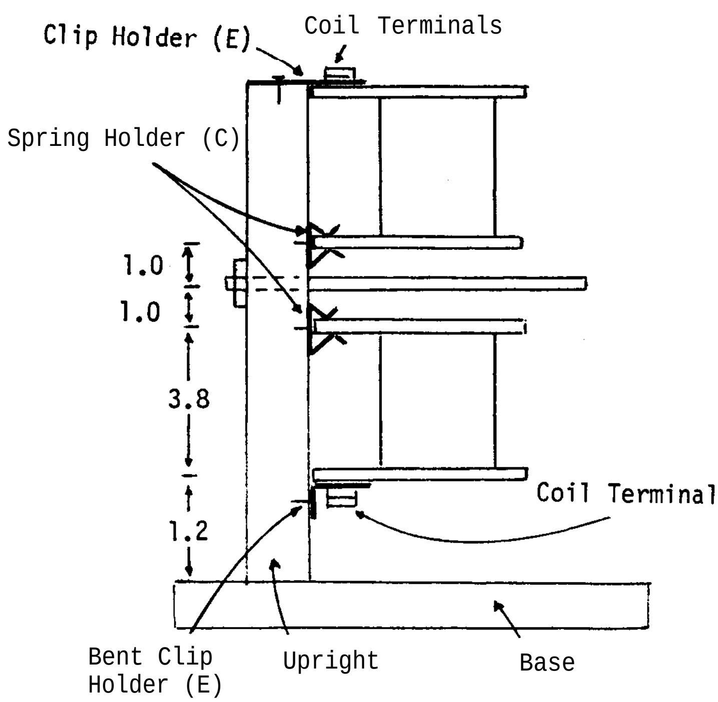
Clip Holder (E)

Cut a slot (0.7 cm x 0.3 cm) in the end of each of the brass sheets (E) and drill a screw hole in the other end, thus producing four clip holders.



Bend two of the holders at right angles to make L-shaped clips as follows.

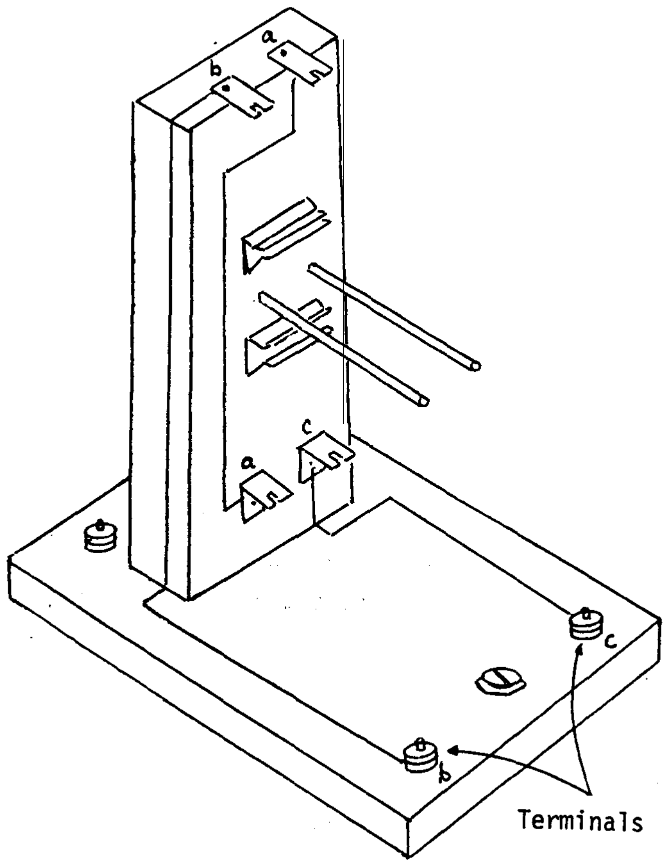
Measure the distance from the center of the coil terminal to the upright. Let's say this is 1 cm. Then the clips must be bent at right angles at 1.3 cm from the slotted end. Fit the slotted end of each clip holder under the locking nut of a terminal on the lower coil, and use screws (F) to attach the clips to the upright.



Use screws (D) to attach the spring holders horizontally to the upright of the apparatus, 1 cm above, and 1 cm below, the horizontal rods. Clip the multipurpose coils temporarily in the spring holders, and mark out the positions of the free endpieces of the coils.

Cut the top off the upright, so that it is level with the top of the upper coil. Take two clips, and fasten the slotted end of each under the locking nut of a terminal on the top end of the coil. Then holding the coil close to the upright, attach the clips to it with small screws (F).

(4) Terminals



Use bolts (G) and nuts (H) to make two terminals, as described under VIII/A2, Component (4). Attach them to the front of the base. Finally connect the terminals and coil holders by magnet wire (I) so that electrical connections exist between points a to a, b to b, and c to c (see diagram), thus insuring that current will flow through the multipurpose coils in the same direction once the terminals at the front of the base are connected into a circuit.

C. Notes

(i) The apparatus may be used to study the relationship between the force exerted on a current carrying conductor and the magnetic field surrounding the conductor. For this purpose a suitable magnetic field may be created by connecting two dry cells (1.5 volts each) and a torch bulb in series with the multipurpose coils. A strong current may be passed through the lightweight roller by momentarily connecting three dry cells in series with the terminals leading to the horizontal rods. Under such conditions the roller will be propelled along the rods.

X. GALVANOMETERS

A. ELEMENTARY GALVANOMETERS

These are extremely simple instruments which illustrate the elementary principles of galvanometry. They may be used as simple measuring devices, but are not designed for accuracy of measurement.

B. FUNCTIONAL TANGENT GALVANOMETERS

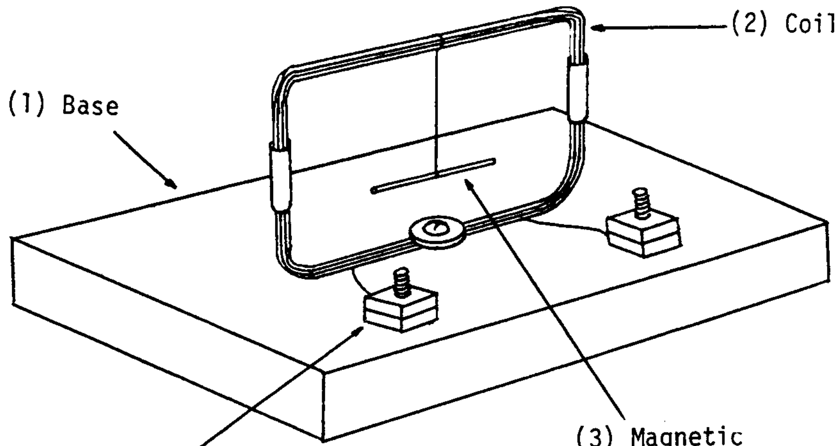
These instruments are probably the most suitable for general use in the school laboratory. They are simple to make and more durable than moving coil galvanometers. In addition, they are surprisingly sensitive,and with the help of shunts may be used for a multiple range of measurements.

C. FUNCTIONAL MOVING COIL GALVANOMETERS

These instruments are quite sensitive,and with the help of shunts may be used for a multiple range of measurements.

A. ELEMENTARY GALVANOMETERS

Al. Elementary Tangent Galvanometer



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	7 c m x 7 c m x l c m
(2) Coil	1	Magnet Wire (B)	#26, 400 cm long
	--	Masking Tape (C)	--
	1	Screw (D)	1 cm long
	1	Washer (E)	--
(3) Magnetic Needle	1	Needle (F)	0.1 cm diameter
	1	Cotton Thread (G)	5 cm long
(4) Terminals	2	Bolts (H)	0.3 cm diameter, 2.5 cm long
	4	Nuts (I)	0.3 cm internal diameter

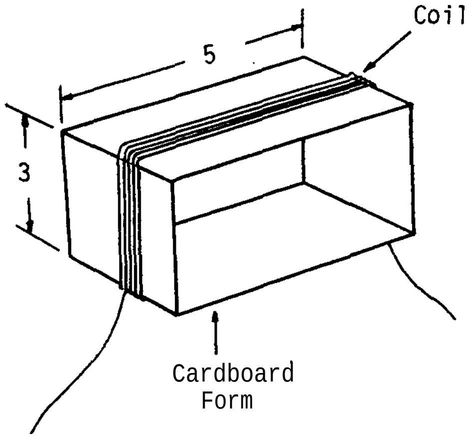
b. Construction

(1) Base

Make the base out of wood (A).

(2) Coil

Wind 20 turns of the magnet wire (B) around a cardboard form to make a rectangular coil (5 cm x 3 cm), leaving about 5 cm of free wire at either end of the coil.



Remove the coil from the form, and wrap sufficient masking tape (C) around the coil to insure that it maintains its shape. Then separate the windings slightly on the bottom side of the coil, mount the coil on the base with the help of a washer (E) and a screw (D) passed through the separated windings.

(3) Magnetic Needle

Magnetize a needle (F) with the help of a magnetizing coil (IX/Al). Cut off about 4 cm of the needle, and suspend it horizontally at the middle of the coil by means of a cotton thread (G) attached to the top of the coil.

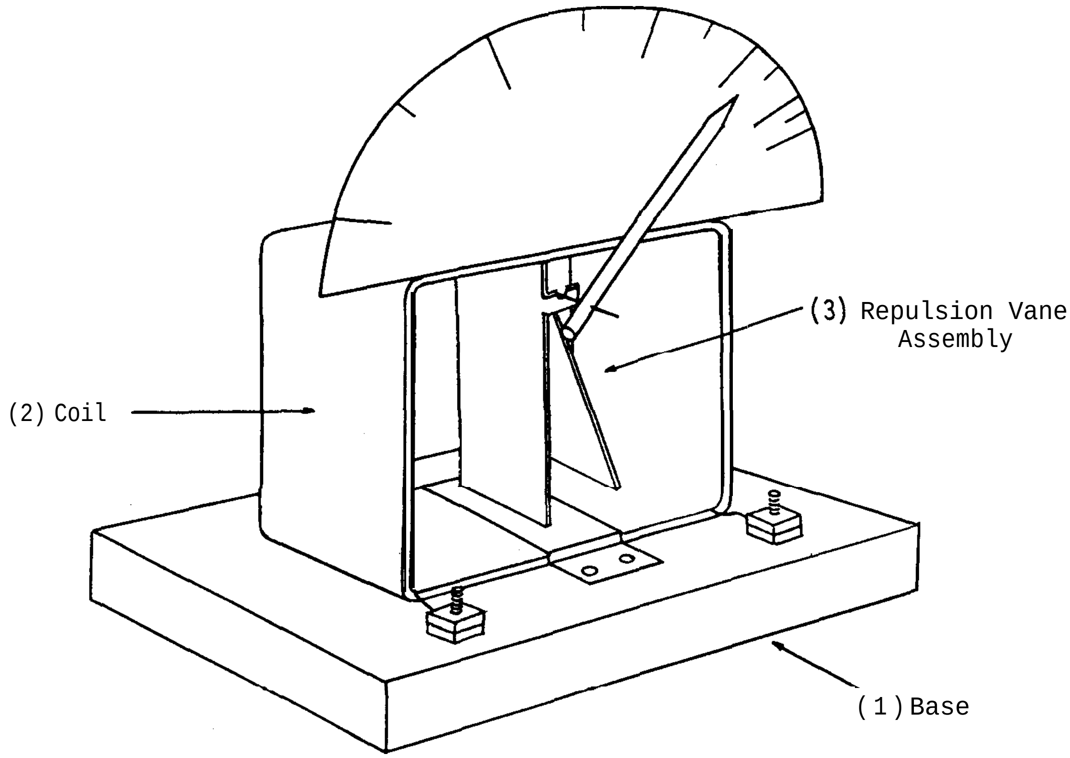
(4) Terminals

Use the bolts (H) and nuts (I) to make two terminals in the base as described under item VIII/AZ, Component (4). Clean the ends of the coil wire with sandpaper, and fasten the wires to the terminals.

C. Notes

(i) Prior to using this apparatus it should be set so that the needle is suspended in the plane of the coil. A current passed through the coil will cause the needle to be deflected away from the plane of the coil, the deflection depending on the magnitude of the current carried by the coil. The apparatus simply illustrates the principle of the tangent galvanometer, and is too crude for specific measurements.

A2. Repulsion Type Galvanometer



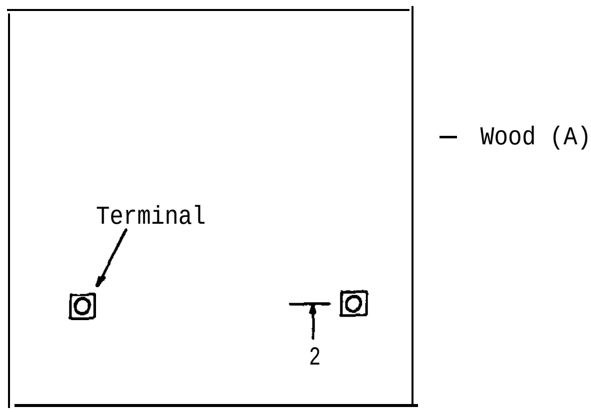
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	10 cm x 10 cm x 1 cm
	2	Bolts (B)	0.3 cm diameter, 2.5 cm long
	4	Nuts (C)	0.3 cm internal diameter
(2) Coil	1	Cardboard Sheet (D)	20 cm x 3.5 cm
	--	Masking Tape (E)	--
	1	Roll of Magnet Wire (F)	#26, (diameter 0.05 cm), 30 meters long
	1	Aluminum Sheet (G)	7 cm x 4 cm x 0.02 cm
	4	Screws (H)	1 cm long
(3) Repulsion Vane Assembly	1	Galvanized Iron Sheet (I)	7 cm x 3.5 cm x 0.02 cm
	1	Galvanized Iron Sheet (J)	4.3 cm x 2.5 cm x 0.02 cm
	1	Needle (K)	8 cm long, 0.1 cm diameter
	--	Masking Tape (L)	--

1	Soda Straw (M)	--
1	Cardboard Sheet (N)	12 cm x 12 cm

b. Construction

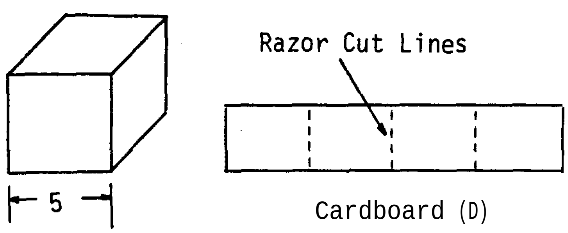
(1) Base



Top View

Make two terminals from bolts (B) and nuts (C) [as described under VIII/A2, Component (4)] and attach them at about 2 cm from the edge of the wood (A). The boltheads of the terminals should be countersunk into the base, so that the latter sits flat on any horizontal surface.

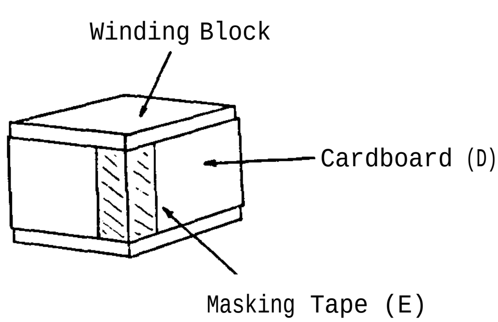
(2) Coil



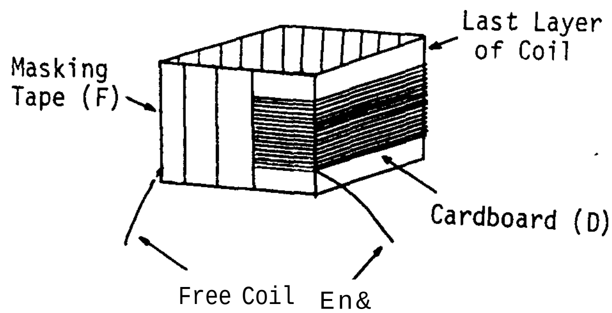
Winding Block

Cardboard (D)

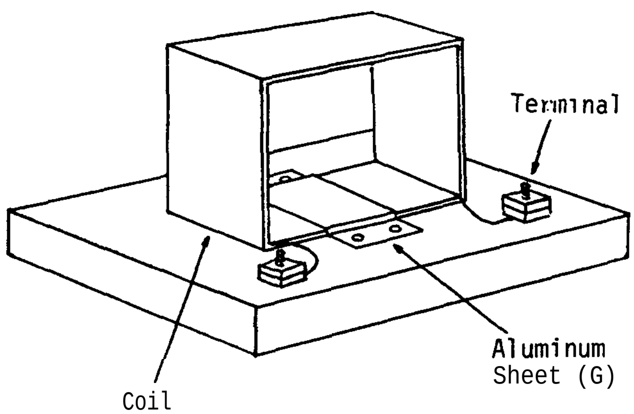
Cut a piece of wood (5 cm x 5 cm x 5 cm) to serve as a winding block for the coil. Use a razor blade to score parallel lines on the cardboard (D) at 5 cm intervals so that it may be readily bent into the shape of the wooden block.



Wrap the cardboard loosely around the block fastening the two loose edges together with masking tape (E).

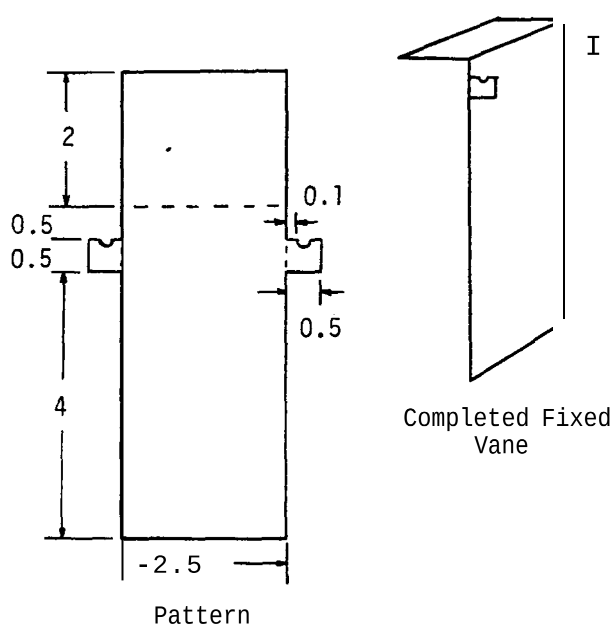


Wind approximately 150 turns of the magnet wire (F) onto the cardboard form. This will take three layers of turns. After winding the turns, remove the cardboard holder (and turns) from the winding block, and cover the turns with masking tape (E) to hold the wire in position. Make sure that about 10 cm of wire is free at both ends of the coil.

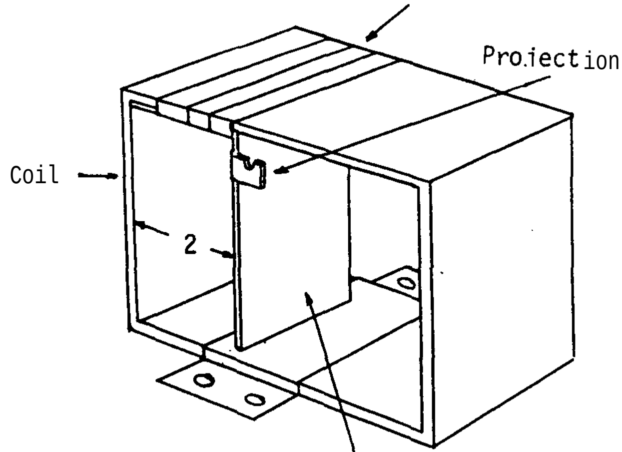


Drill two holes (diameter 0.2 cm) at either end of the aluminum sheet (G). Set the coil in a vertical plane on the base, and strap it in position with the help of the aluminum sheet (G) and four screws (H). Bare the ends of the wire, and attach them to the terminals on the base.

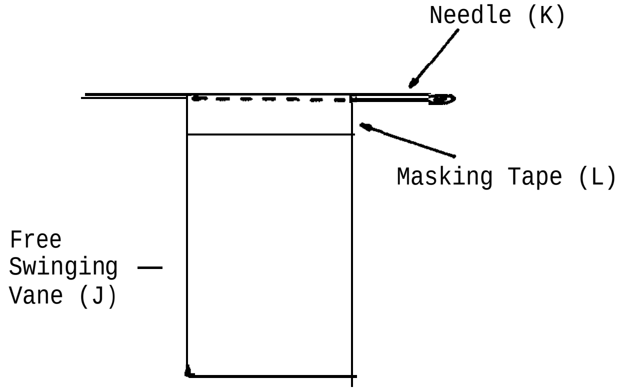
(3) Repulsion Vane Assembly



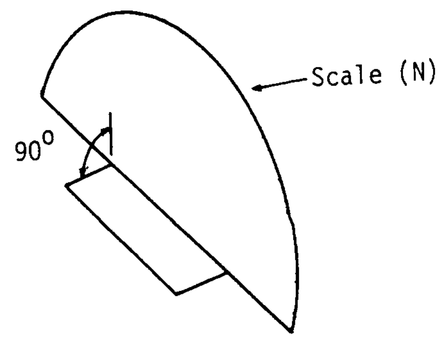
Two vanes are required, one fixed and one free swinging. The fixed vane may be cut from a sheet of galvanized iron (I) according to the dimensions indicated. The cut sheet resembles a vertical cross. Drill a hole (0.2 cm diameter) in the top edge of each of the horizontal portions of the cross (see illustration). Then bend the sheet at right angles along the lines indicated.



The completed vane may then be fixed vertically in position within the coil by wrapping masking tape (L) around the top of the coil, covering the horizontal portion of the fixed vane in the process.

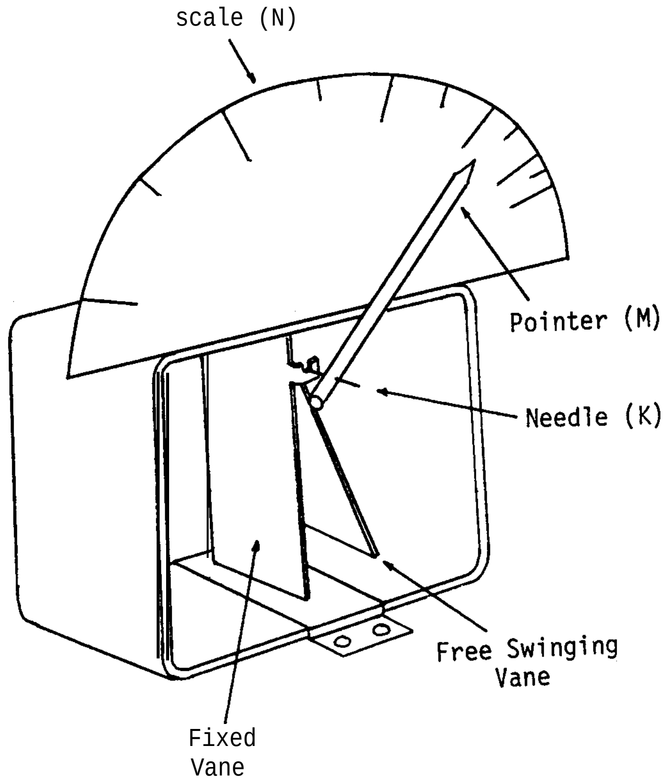


The free swinging vane is made from the other sheet of galvanized iron (J) and suspended from the middle of the needle (K) by wrapping a piece of masking tape (L) over the end of the vane. Suspend the vane from the projections on the fixed vane.



Back View

Make a pointer from the straw (M), and pivot it on the needle (K) at about 2 cm from the end of the straw. Make the scale from the cardboard (N), bending the bottom of the scale at right angles to form a horizontal flap. Use masking tape to attach the flap (and hence the scale) to the top of the coil.



c. Notes

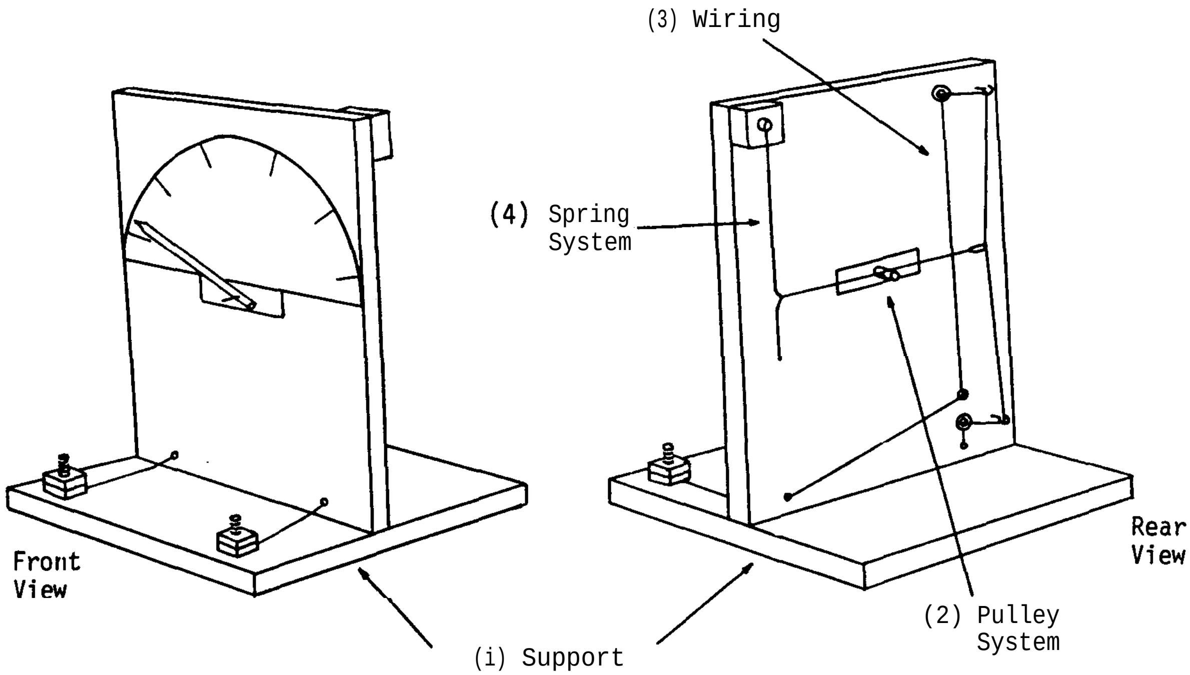
(i) The ga vanometer may be calibrated by placing it in series with an ammeter (0 - 5 amps), a voltage supply (dry cells, battery, etc.) and a variable resistance

(ii) The resulting scale will be nonuniform, the separation of points on the scale increasing with increasing amperage. The range of the scale for this particular design will be approximately 0 to 3 amps (DC).

(iii) The galvanometer will measure both DC and AC current equally well, since the repulsion of the vanes is independent of the direction of the current in the coil.

(iv) The resistance of the galvanometer is approximately 2.5 ohms. The current existing in a circuit will therefore be affected in general by the addition of the galvanometer to the circuit.

A3. Hot Wire Ammeter



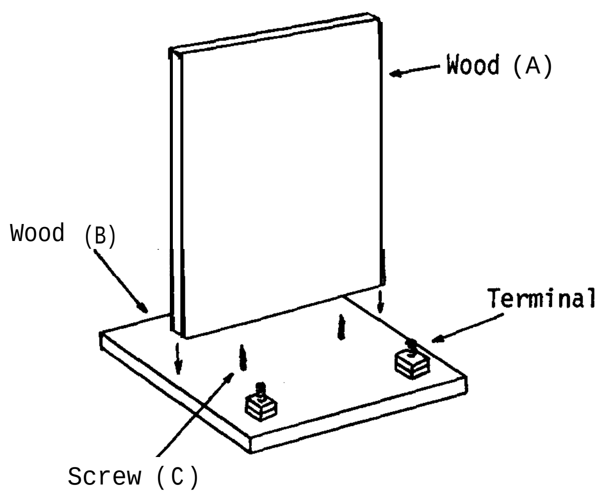
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	1	Wood (A)	20 cm x 12 cm x 2 cm
	1	Wood (B)	12 cm x 12 cm x 2 cm
	2	Screws (C)	3 cm long
	2	Bolts (D)	0.3 cm diameter, 3.5 cm long
	4	Nuts (E)	0.3 cm internal diameter
(2) Pulley System	2	Aluminum Sheets (F)	5 cm x 2 cm x 0.05 cm
	4	Screws (G)	1 cm long
	1	Needle (H)	5 cm long, 0.1 cm diameter
	1	Wooden Dowel (I)	0.5 cm diameter, 1 cm long
	1	Soda Straw (J)	--
	1	Cardboard Sheet (K)	12 cm x 6 cm
(3) Wiring	2	Eye Screws (L)	--
	3	Wood Screws (M)	1.5 cm long
	2	Washers (N)	--
	1	Nichrome Wire (0)	#30, 22 cm long, 0.02 cm diameter

	1	Copper Wire (P)	#24, 50 cm long
(4) Spring System	1	Wood (Q)	2 cm x 2 cm x 1 cm
	1	Steel Wire (R)	#16, diameter 0.12 cm, length 12 cm
	1	Screw (S)	1 cm long
	1	Thread (T)	10 cm long
	1	Paper Clip (U)	Approximately 1 cm long

b. Construction

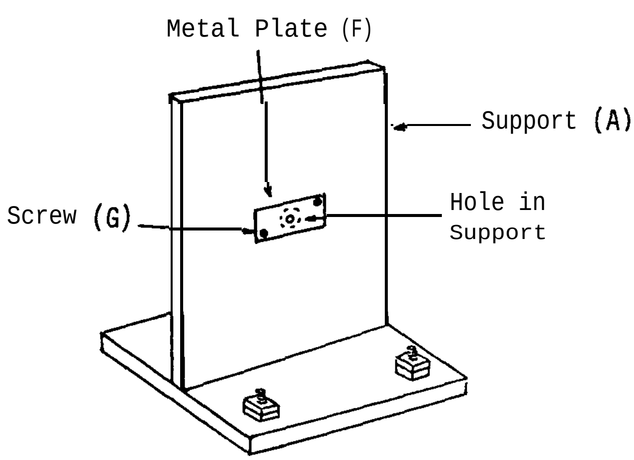
(1) Support



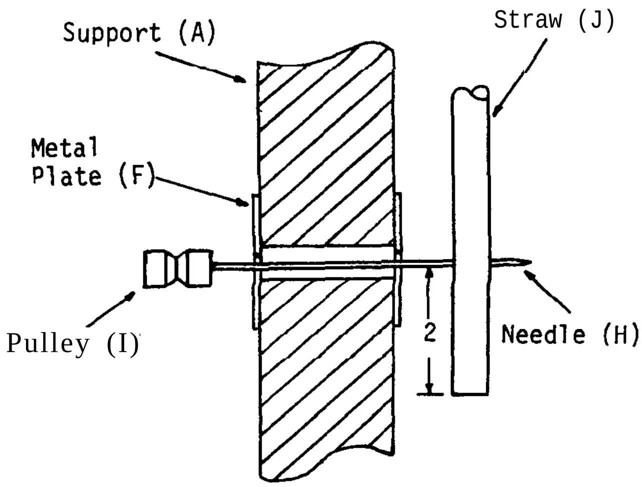
Attach the vertical component (A) to the middle of the base (B) with the help of screws (C) and wood cement.

Use the bolts (D) and nuts (E) to make two terminals [as described under VIII/AZ, Component (4)] and attach these to the front of the base. The boltheads of the terminals should be countersunk into the bottom of the base (B) so that the latter sits flat on any horizontal surface.

(2) Pulley System



Drill a hole (diameter 0.5 cm) through the exact middle of the vertical component (A) of the support. Drill a hole (diameter 0.2 cm) through the center of each of the aluminum plates (F) to serve as pivot holes for the pointer. Drill two holes (diameter 0.2 cm) in diagonally opposite corners of each plate, so that the latter may be screwed onto either side of the support over the centrally drilled hole. The holes in the plates should be at the same height on both sides of the support, so that the needle (H) may be pivoted horizontally through the holes.



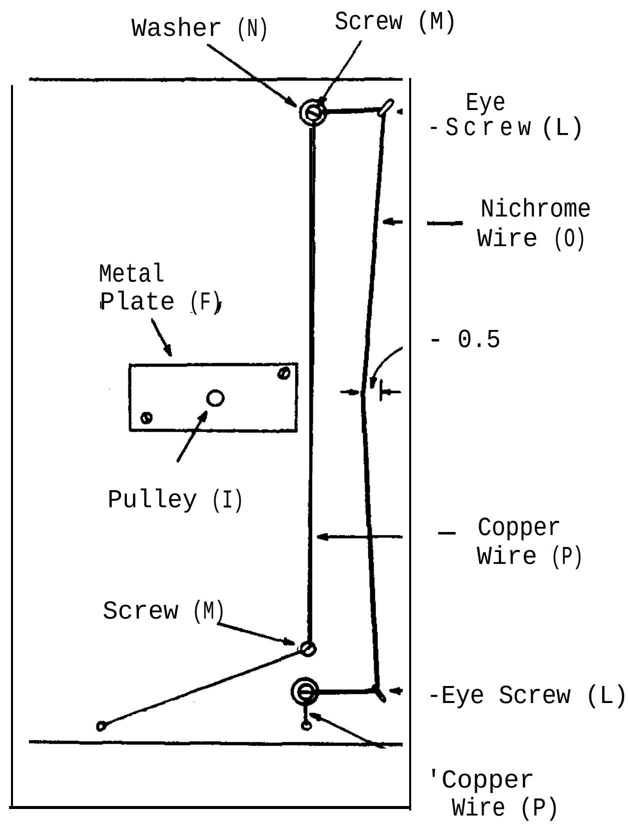
Cross Section

Use a file and sandpaper to make a groove in the wood dowel (I) forming a pulley, thus preventing string from slipping off it. Drill a small hole in the end of the pulley (I) so that it may be slipped onto the end of the needle (H), and fix it firmly in position with the help of glue.

Make a pointer from the soda straw (J) and attach it to the needle about 2 cm from the end of the straw.

Cut a semicircular scale (diameter 12 cm) out of cardboard (K), and glue it to the vertical support behind the pointer.

(3) Wiring



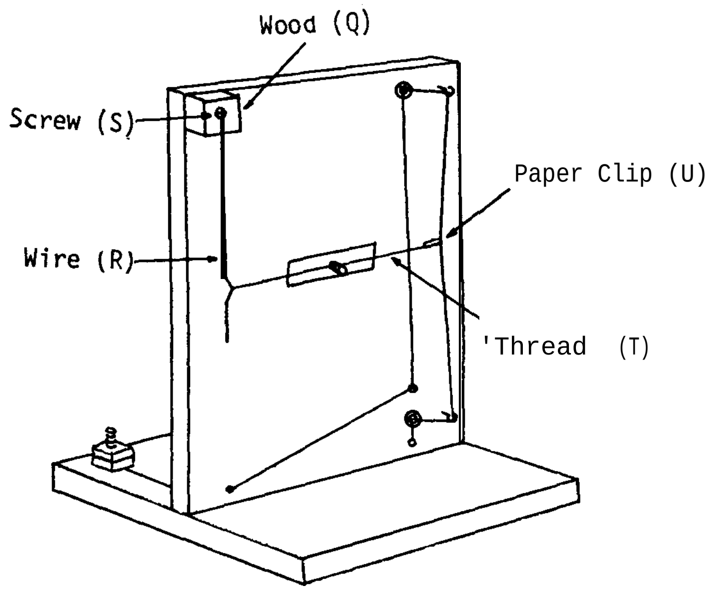
Back View

Fix two eye screws (L) into the rear right-hand side of the support. About 2 cm to the left of each eye screw fix a small wood screw (M) and a washer (N).

Connect the nichrome wire (O) from one wood screw, through both eye screws, to the other wood screw. The length of the wire should be adjusted so that it needs to be pulled about 0.5 cm from the vertical, at its center point, in order to make it completely taut.

Drill two holes in the vertical component of the support to carry electrical wire from the rear of the support to the front. Make one hole (0.2 cm diameter) through the support about 1 cm beneath the bottom wood screw and a second hole at the same height, but on the left side of the support. Connect a length of copper wire (P) from the lower wood screw, through the nearest hole in the support, to the nearest terminal at the front of the base. Connect a second length of wire (P) from the upper wood screw, through the second drill hole, to the remaining terminal. It is convenient to keep the second copper wire away from the middle of the support and the pulley system, with the help of a third wood screw (M).

(4) Spring System



Back View

Attach the small wood block (Q) to the rear of the support at the top left-hand corner. Insert a screw (S) into the block and fasten the end of a length of steel wire (R) between the screw and block so that the wire is held rigidly in a vertical position, thus serving as a spring.

Attach the thread (T) at one end to the middle of the hot wire (0) with the help of a small paper clip (U). Wrap the thread around the pulley (I) once, and then tie the free end onto the spring wire (R). In order to do this make a small kink in the steel wire at the point of attachment of the thread, thus preventing the latter from slipping, and during the tying of the thread, make sure that the spring wire is pulled towards the hot wire. This insures that the thread is always under tension, and that the pulley (and hence pointer) responds readily to any movement of the hot wire.

C. Notes

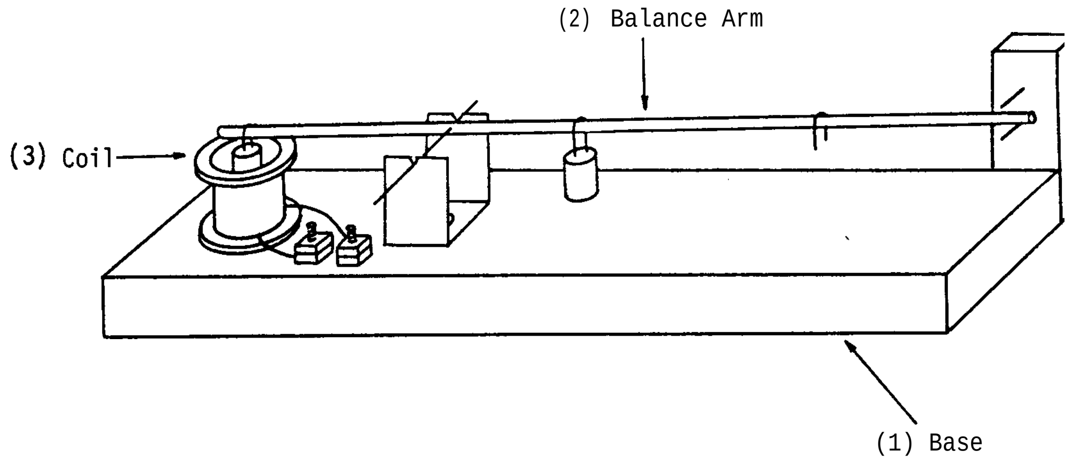
(i) The galvanometer may be calibrated by placing it in series with an amneter (0 - 5 amps), a voltage supply (dry cells, battery, etc.) and a variable resistance.

(ii) The resulting scale will be nonuniform,the separation of points on the scale increasing with increasing amperage. The range of the scale for this particular design will be approximately 0 to 1.5 amps (DC).

(iii) The galvanometer will measure both DC and AC current equally well, since the extension of the hot wire (and hence the movement of the pointer) is dependent on the heating of the wire, which in turn is proportional to the square of the current passing through the wire.

(iv) The resistance of this galvanometer is approximately 4.5 ohms.

A4. Current Balance

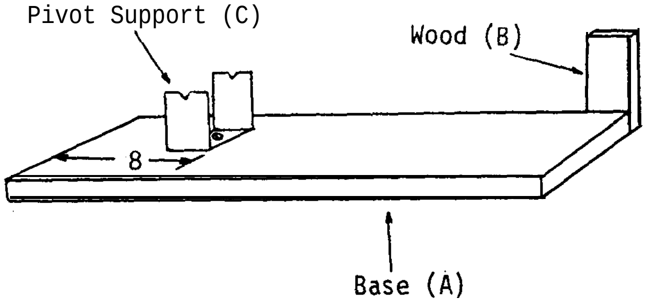


a. Materials Required

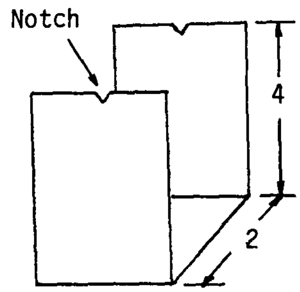
Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	22 cm x 5 cm x 2 cm
	1	Wood Strip (B)	6 cm x 2 cm x 0.5 cm
	1	Aluminum Sheet (C)	10 cm x 2 cm x 0.05 cm
	1	Screw (D)	1 cm long
(2) Balance Arm	1	Needle (E)	4 cm long, 0.1 cm diameter
	1	Soda Straw (F)	21 cm long, approximately
	1	Nail (G)	0.4 cm diameter
	1	Magnet Wire (H)	#30, 10 cm long
	--	Masking Tape (I)	--
	2	Pins (J)	--
(3) Coil	1	Sheet of Paper (K)	10 cm x 2 cm
	1	Cardboard Sheet (L)	2 cm x 2 cm
	1	Magnet Wire (M)	#22, 400 cm long
	--	Masking Tape (N)	--
	2	Bolts (O)	0.3 cm diameter, 3.5 cm long
	4	Nuts (P)	0.3 cm internal diameter

b. Construction

(1) Base



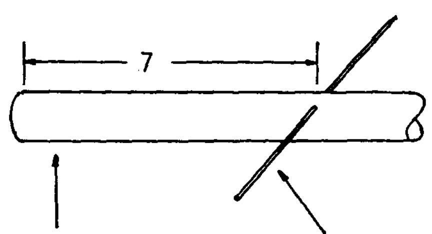
Fasten an upright piece of wood (B) to the rear of the base (A), and to one side. Make a pivot support from the sheet of aluminum (C). Drill a hole (diameter 0.2 cm) in the middle of the horizontal portion of the support, and attach it to the base with the screw (D).



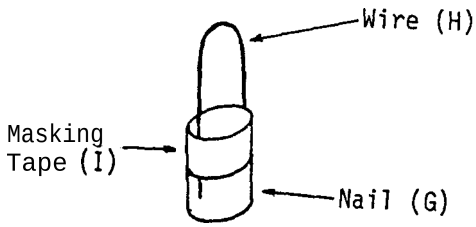
Pivot Support (C)

Using a small file cut a shallow, smooth notch in the top of each side of the support to hold a subsequent needle pivot in position.

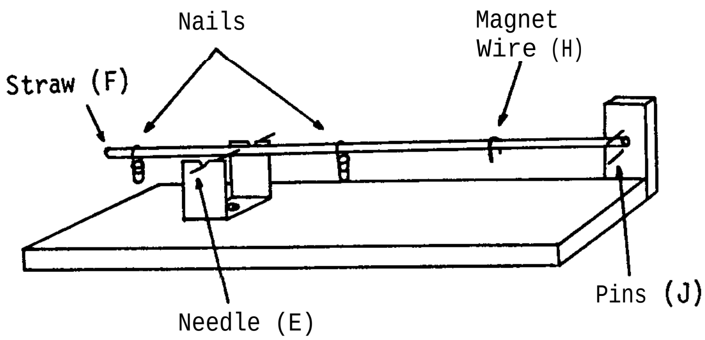
(2) Balance Arm



Insert the needle (E) through the top edge of soda straw (F) at a distance of 7 cm from one end. Balance the straw on the support.



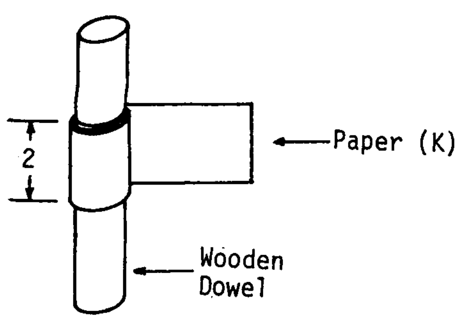
Cut two lengths from the nail (G), one 1.0 cm long and one 2.0 cm long. Attach a three centimeter-long loop of the magnet wire to the end of each nail with the help of a strip of masking tape the short nail at the end of the short arm of the straw, and hang the long nail at an appropriate point on the other side of the pivot to serve as a counter-balance. A drop of glue (or a small piece of masking tape) can insure that the loops do not slip along the straw.



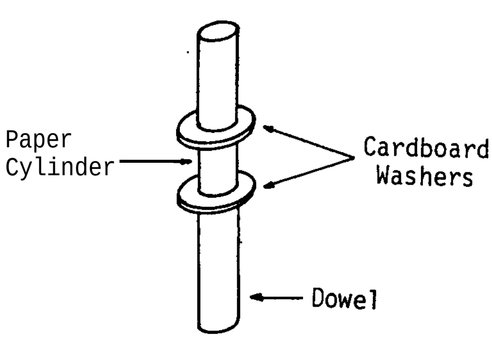
With the straw balanced horizontally note the corresponding point on the upright (B). Insert two pins (J) horizontally into the upright, one pin 0.5 cm above the top surface of the balanced straw, and the other 0.5 cm below the bottom surface, thus restricting the motion of the end of the straw to about 1 cm.

Set a length of magnet wire (M) on the straw to serve as a rider (see notes).

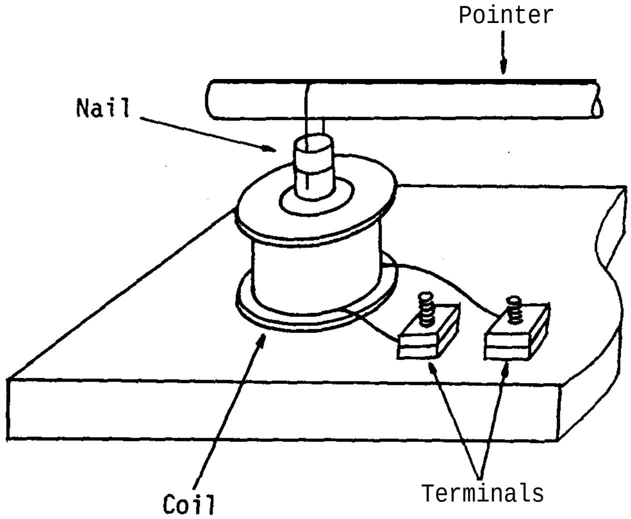
(3) Coil



Wrap the paper (K) around a wooden dowel (1.0 cm diameter) to make a paper cylinder. Secure the Joose ends of the paper with masking tape (N).



Cut two washers (internal diameter 1.0 cm, external diameter 2.0 cm) from the sheets of cardboard (L). Attach the washers to the ends of the paper cylinder with glue.



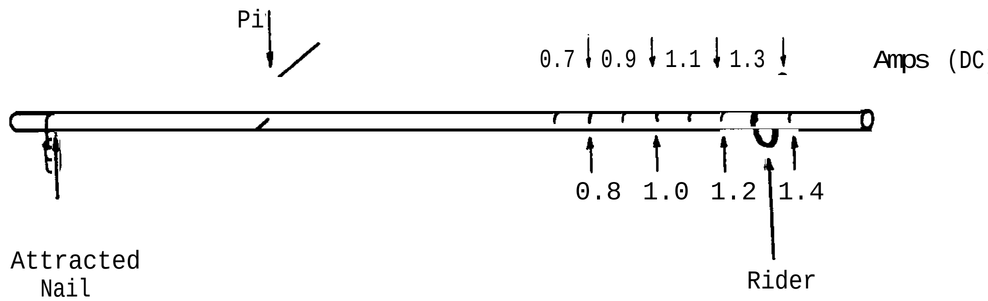
Wind the magnet wire (M) onto the paper cylinder to make a coil. Leave 10 cm of wire free at either end. Cover the last layer of wire with masking tape (N) to hold the coil in position. Remove the coil from the dowel, and mount it on the end of the base with glue in such a way that the axis of the coil is directly beneath the nail suspended from the end of the straw balance arm.

Drill two holes (diameter 0.3 cm) in the base at any convenient point close to the coil, and make two terminals from the nuts (P) and bolts (O) as described under VIII/A2, Component (4). Fit the terminals in the two holes, and connect the wires from the coil to the terminals.

c. Notes

(i) The galvanometer may be calibrated by placing it in series with an ammeter, a voltage supply and a variable resistance noting the position of the rider each time the straw balance arm is balanced and noting simultaneously the corresponding current through the coil.

(ii) A whole range of different scales may be produced simply by changing the mass of the rider on the balance arm. One such scale is illustrated below when the rider used was a 25 cm length of #26 magnet wire coiled into a loop, approximately 1 cm diameter.

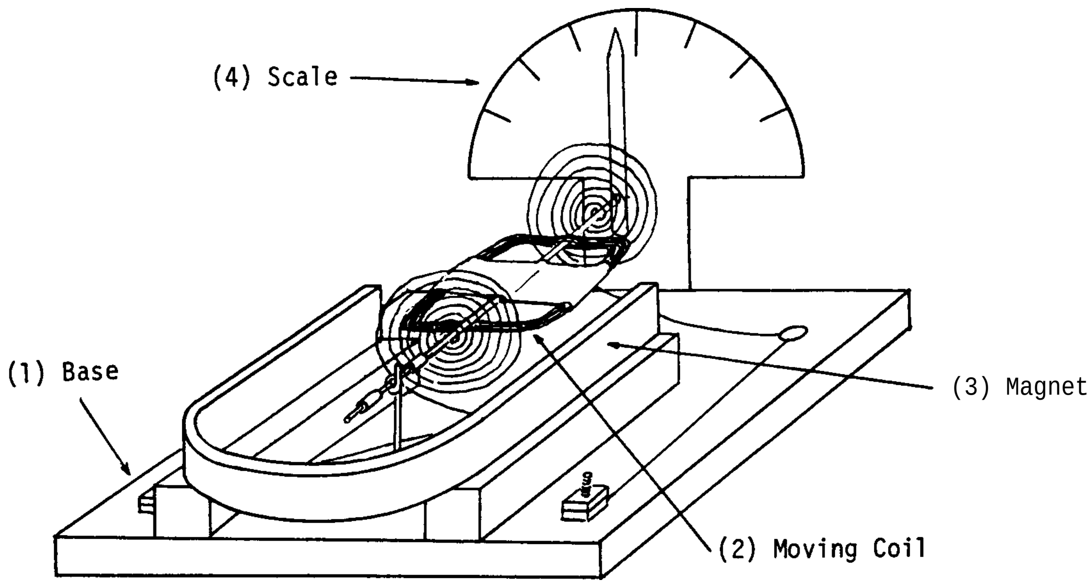


(iii) The resultant scale on the straw is linear. In other words, doubling the current passing through the coil doubles the force exerted by the coil on the nail, and the distance between the rider and pivot must be doubled to reestablish the balance of the straw.

(iv) The galvanometer will measure AC and DC currents equally well since the direction of the attraction exerted by the coil is not dependent on the direction of the current through the coil.

(v) The resistance of the galvanometer is approximately 0.1 ohms.

A5. Elementary Moving Coil Galvonometer

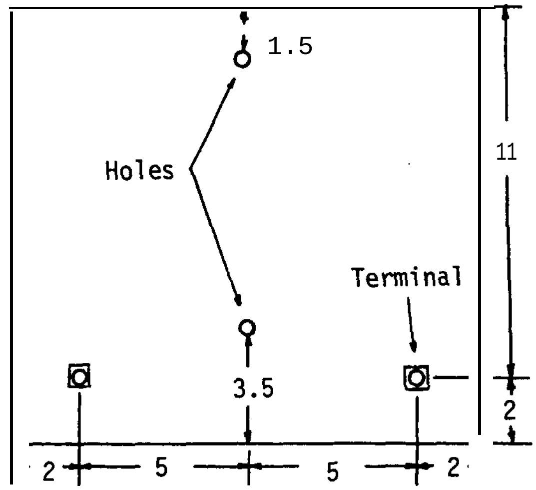


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	14 cm x 13 cm x 1.5 cm
	2	Bolts (B)	0.3 cm diameter, 3.0 cm long
	4	Nuts (C)	0.3 cm internal diameter
	2	Coat Hanger Wire (D)	7 cm long, 0.2 cm diameter
(2) Moving Coil	1	Roll of Magnet Wire (E)	#26
	1	Coat Hanger Wire (F)	10 cm long, 0.2 cm diameter
	1	Masking Tape (G)	--
	2	Thumbtacks (H)	--
(3) Magnet	1	Horseshoe Magnet (I)	--
	2	Wood Strips (J)	Approximately 8 cm x 1.5 cm x 1.0 cm
(4) Scale	1	Straw (K)	6 cm long
	1	Cardboard Sheet (L)	10 cm x 10 cm

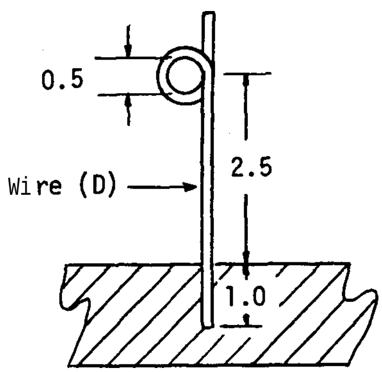
b. Construction

(1) Base



Wood (A)

Make two terminals [see VIII/A2, Component (4)] from the nuts (C) and bolts (B), making sure to inset the boltheads into the bottom of the wood (A). Drill two holes (0.2 cm diameter, 1.0 cm deep) into the base to hold the vertical supports.

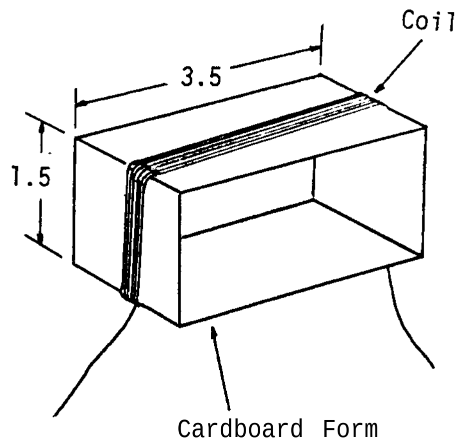


Side View

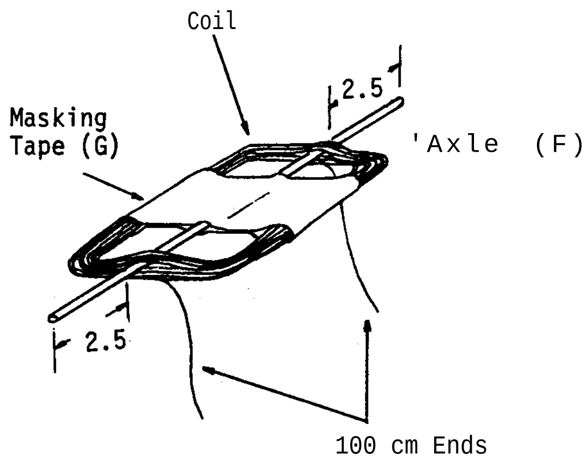
(Cross-section)

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.

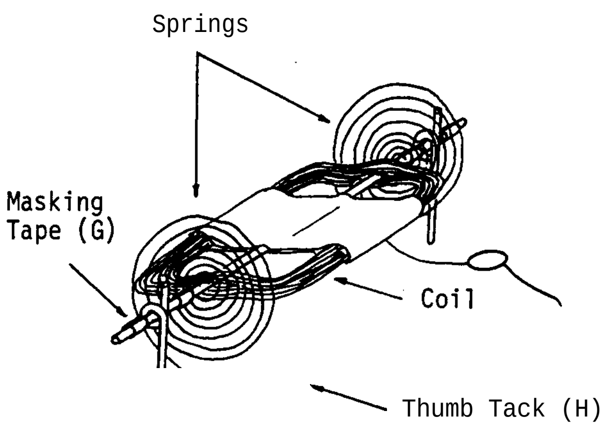
(2) Moving Coil



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 100 cm of wire free at either end of the coil.

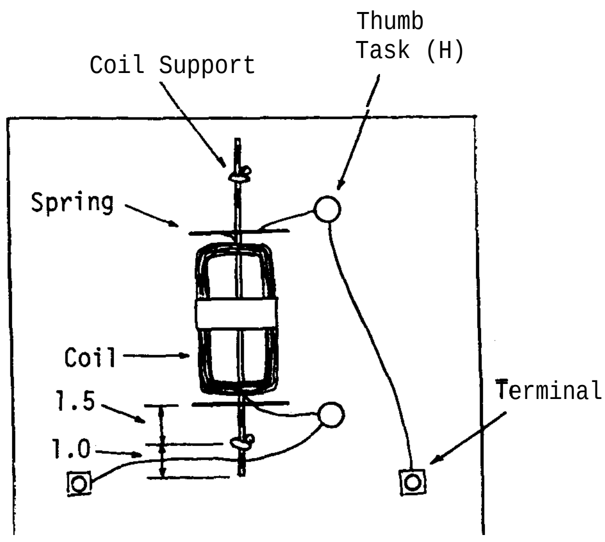


Thread the wire (F) through the middle of the coil to serve as the axle for the coil. Wrap masking tape (G) around the coil and axle to hold the coil firmly in position.



Coil Support (D)

Fit the coil (F) into the coil supports (D) on the base. Wind the 100 cm of magnet wire (E) at either end of the coil into a spring, and attach the wire, just beneath each spring, to the base with the help of a thumb-tack (H). Each spring should contain about eight turns and be about 3 cm in diameter.



Top View

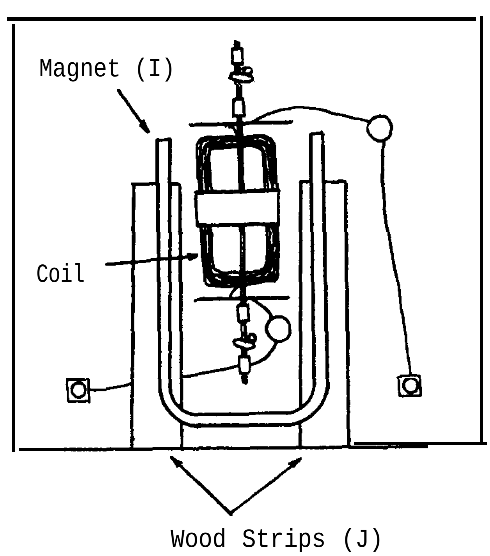
(The sensitivity of the moving coil increases with increasing number of turns and increasing diameter of the spring.) Connect the wire from the springs to the terminals on the base.

Prevent slipping of the axle on the supports by wrapping masking tape around the axle either side of one of the supports.

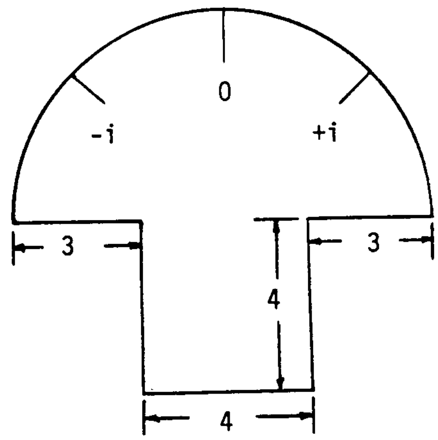
(3) Magnet

Procure a horeseshoe magnet (I) with pole heads at least 4 cm apart, and place it as shown around the coil. Make two wooden strips (J) which, when placed under the magnet, will bring the pole heads up to the same height as the coil. The ends of the magnet should be located opposite the middle of the coil.

Top View



(4) Scale



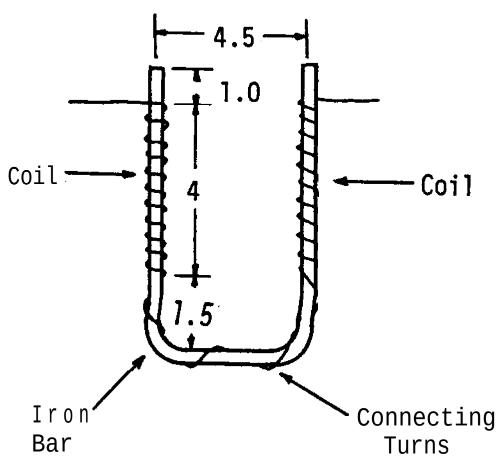
Take the straw (K) and, after piercing it 1 cm from one end, fit it on the end of the axle. A little glue will fix it firmly in position. Cut a suitable scale out of cardboard (L), and attach it to the base, so that it stands just behind the pointer.

C. Notes

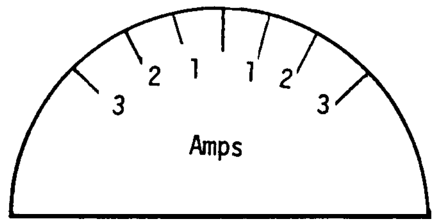
(i) The galvanometer may be calibrated by placing it in series with an ammeter, a voltage source and a variable resistance. The sensitivity of the galvanometer will depend very much on the strength of the horseshoe magnet used.

(ii) The galvanometer will measure DC current, but not AC.

(iii) If a suitable horseshoe magnet is not available, an electromagnet may readily be made. To do this, take a soft iron bar (17.5 cm x 2.0 cm x 0.3 cm), and bend it into a horseshoe shape as indicated. Take about 100 g of #26 magnet wire, 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. The coils may be held in position by means of masking tape. If the coil is connected in series into a separate electrical circuit, it may be used in precisely the same way as the former horseshoe magnet.



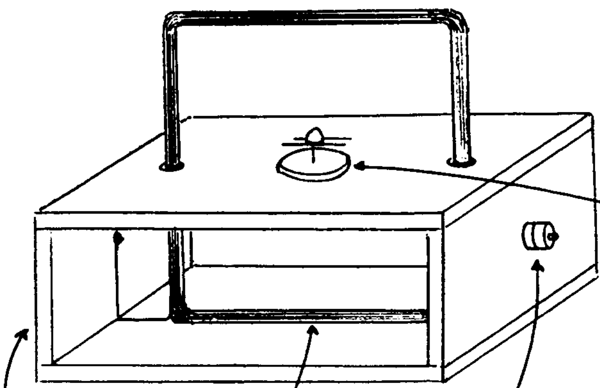
(iv) With a current of 0.5 amps through the electromagnet coils, a 2-amp current through the moving coil produced a deflection of approximately 30°. When the current through the electromagnet was increased to 1.0 amp, the deflection, due to a 3-amp current through the moving coil, increased to 45°.



Electromagnet Current Of Lamp

B. FUNCTIONAL TANGENT GALVANOMETERS

B1. Tangent Galvanometer ©



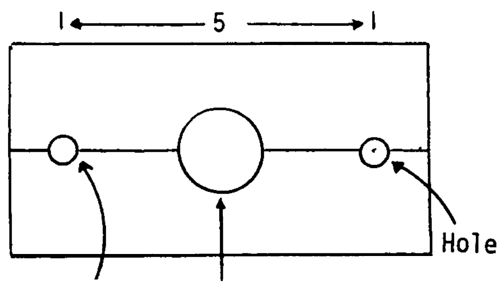
a. Materials Required

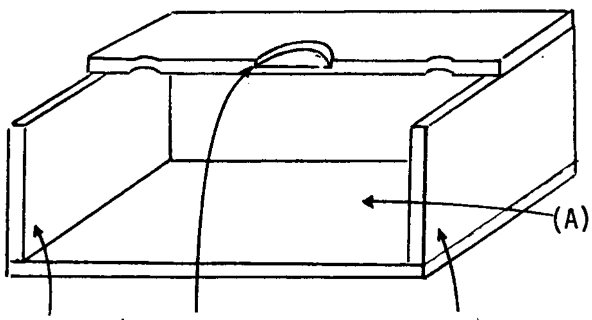
Components	Qu	Items Required	Dimensions
(1) Box Support	1	Wooden Base (A)	12cm x 6cm x 1cm
	2	Wooden Sides (B)	6cm x 2cm x 1cm
	1	Wooden Platform (C)	12cm x 6cm x 1cm
	18	Small Wood Screws (D)	1.5 cm long
(2) Coil	1	Roll of Magnet Wire (E)	#24
	--	Varnish (F)	--
(3) Terminals	2	Brass Bolts (G)	0.3 cm diameter, 2 cm long
	4	Nuts (H)	0.3 cm internal diameter
(4) Compass	1	Wood Disc (I)	2.5 cm diameter, 0.3 cm thick
	3	Needles (J)	0.1 cm diameter
	1	Brass Rod (K)	0.5 cm diameter, 0.5 cm long

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 143-145.

b. Construction

(1) Support

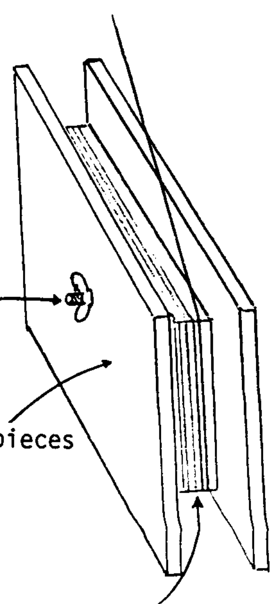




Make a four-sided wooden support from the wooden base (A), wooden sides (B) and platform (C). Fasten the base and sides together with small screws (D) and wood cement, but do not put the platform in position yet.

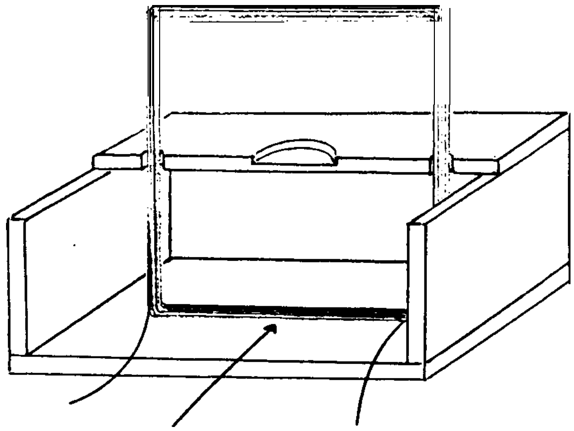
Drill an inset (2.5 cm diameter, 0.2 cm deep) into the middle of the platform, and two holes (1 cm diameter) right through the platform to take the coil. Cut the platform into two equal halves, fastening one half only in position with small screws and wood cement.

(2) Coil



To make the coil a simple winding device is desirable. This may be made from a block of wood (5 cm x 5 cm x 1 cm) and two cardboard sides (8 cm x 8 cm x 0.5 cm). Drill a hole through the middle of the block and sides and hold the parts together with a bolt and wing nut.

Wind 100 turns of magnet wire (E) onto the block, layer by layer, adding a coat of varnish (F) to each layer to hold the turns together. Make sure that about 20 cm of both ends of the



wire are left free to make appropriate connections.

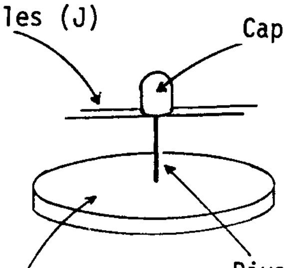
When the varnish is dry remove the coil from the block (simply by releasing the sides) and sit the coil vertically in the support.

Attach the second half of the platform with small wood screws and wood cement.

(3) Terminals

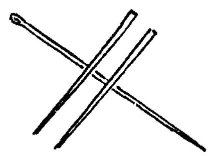
Use bolts (G) and nuts (H) to make two terminals as described under VIII/A2, Component (4). Fix one on either side of the support, and attach the two wires from the coil to the terminals. Don't forget to clean the ends of the wire with sandpaper.

(4) Compass



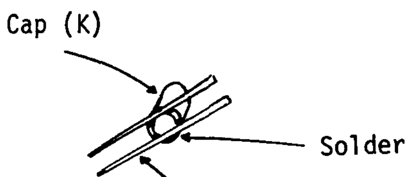
Use the wood disc (I) as the base of the compass. Alternatively, a cork disc would serve equally well, although less durable.

Cut a 1 cm length off the pointed end of a needle (J). Drill a small hole (0.1 cm diameter) in the middle of the base and set the needle in the hole with epoxy resin so that it stands vertically, pointed end uppermost.



Holding rod (K) firmly in a clamp, drill a hole (0.3 cm diameter) 0.3 cm deep along the axis. You now have a suitable cap to sit on the pivot.

Cut 2 cm lengths off the two remaining needles (J). Determine the center of gravity of each by balancing the needles over another needle. Mark in the position of the center of gravity of each of the two needles.



Hold the needles parallel to one another and drop some solder on the base of the cap. Innnediately attach the needles (at their centers of gravity) to the cap by placing them in the still molten solder.

Finally, place the cap and needles inside a magnetizing coil (IX/A2) to magnetize them, and then place them on top of the pivot.

Note the ends of the needles which point to the North, and mark these (e.g., with paint).

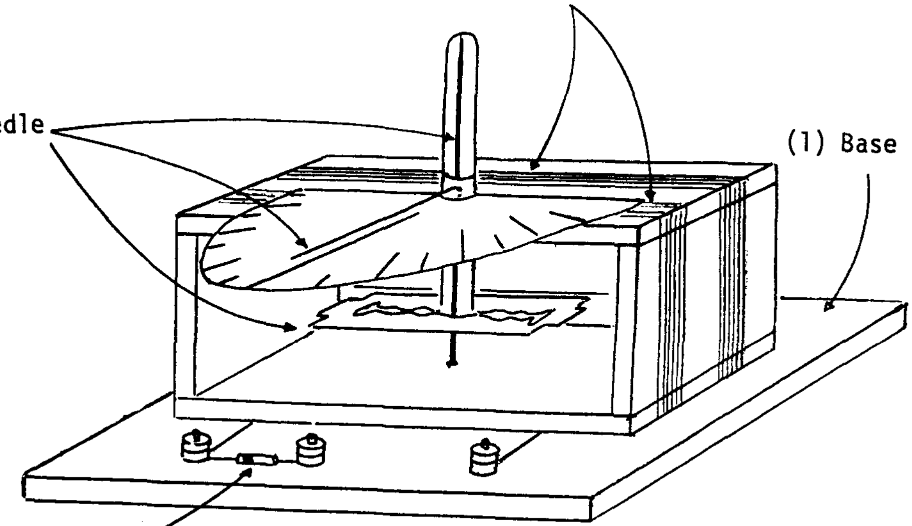
C. Notes

(i) The galvanometer should be set so that the plane of its coil is in a North-South direction, as indicated by the compass needle. A current passing through the coil will cause the needle to be deflected out of this plane, the angle of deflection depending on the strength of the current.

(ii) It is important that magnets and iron should be kept well away from the galvanometer during use to avoid influencing the compass needle.

(iii) The galvanometer will readily detect the differences in magnitude of currents produced by the various combination of plates and electrolytes in the Chemical Cell (VIII/Al).

B2. Tangent Galvanometer with Shunts *



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	10 cm x 10 cm x 1 cm
	2	Bolts (B)	0.3 cm diameter, 2.5 cm long
	4	Nuts (C)	0.3 cm internal diameter
(2) Coils	2	Wood (D)	8 cm x 5 cm x 0.5 cm
	2	Wood (E)	3 cm x 5 cm x 0.5 cm
	1	Magnet Wire (F)	#26 (diameter 0.05 cm), length approximately 16 meters
	--	Masking Tape (G)	--

*Adapted from Fr. George Schwarz, A Don Bosco Laboratory Manual, (Philippines: Unpublished Papers).

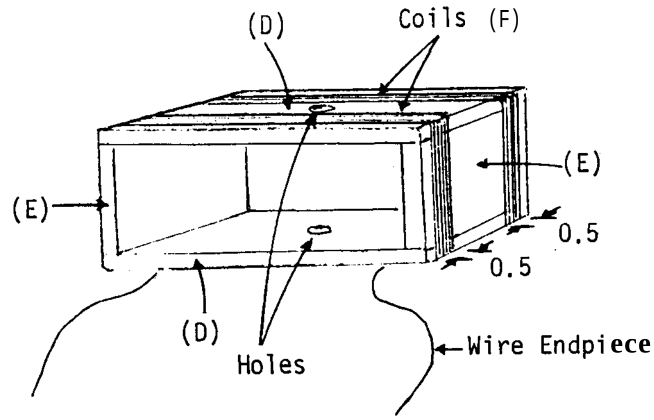
(3) Magnetic Needle Assembly	1	Needle (H)	10 cm long, 0.1 cm diameter
	1	Razor Blade with Double Edges (I)	--
	1	Glass Tube (J)	6 cm long, 0.5 cm external diameter
	2	Screws (K)	1.5 cm long
	1	Cardboard Sheet (L)	2.5 cm x 2.0 cm
	1	Pin (M)	2.5 cm long, approximately
	3	Cardboard Sheets (N)	B cm x 4 cm
(4) Shunts	1	Nichrome Wire (O)	#24, 0.17 ohms (approximately 5 cm long)
	1	Resistor (P)	1,000 ohms (from radio shop)
	1	Bolt (Q)	0.3 cm diameter, 2.5 cm long
	1	Nut (R)	0.3 cm internal diameter

b. Construction

(1) Base

Drill two holes (diameter 0.3 cm) in Wood (A) about 3 cm apart and close to one edge to take the terminals. Use bolts (B) and nuts (C) to make two terminals as described under VIII/A2, Component (4), and fit them through the holes in the base. The boltheads should be countersunk into the bottom of the base so that the latter sits flat on any horizontal surface.

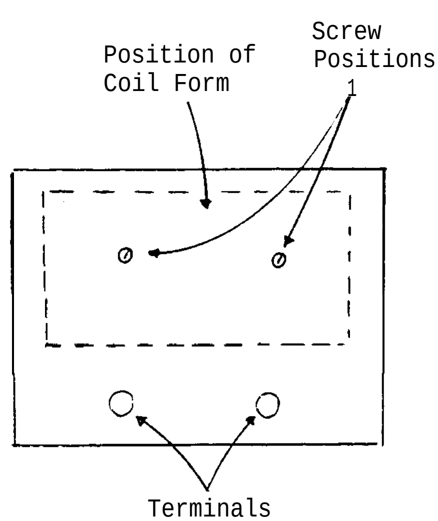
(2) Coils



Make a wooden form using wood (D) for the top and base and wood (E) for the side pieces. Glue the pieces together.

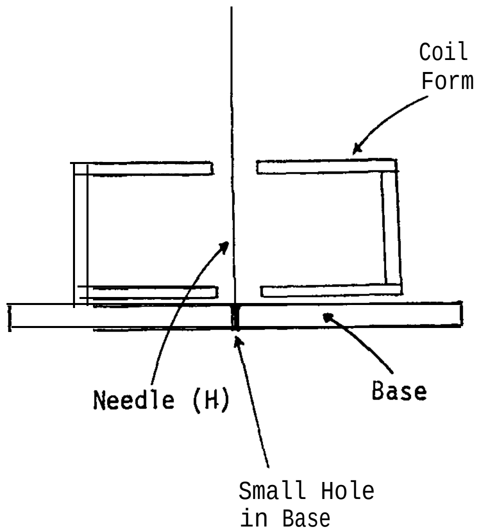
Drill a hole (1.0 cm diameter) in the middle of the top, and an identical hole (1.0 cm diameter) directly beneath in the middle of the base of the form.

Wind magnet wire (F) around the form to make two coils which are connected in series to one another, and which are wound in the same direction around the form. Wind 20 turns of wire into each coil, and locate these close to the opposite edges of the form. Make sure that about 10 cm of each end of the wire is left free. After winding the coils, cover the final layer of turns with a layer of masking tape (G) to hold the coils in position.

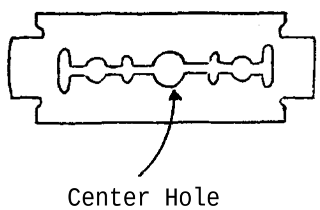


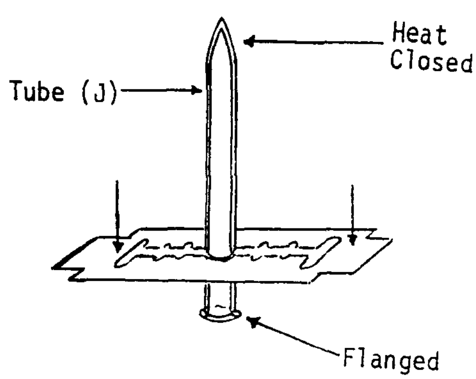
Drill two appropriate holes through the base in order to attach the coil form to the base with screws, but do not screw the form on to the base yet.

(3) Magnetic Needle Assembly

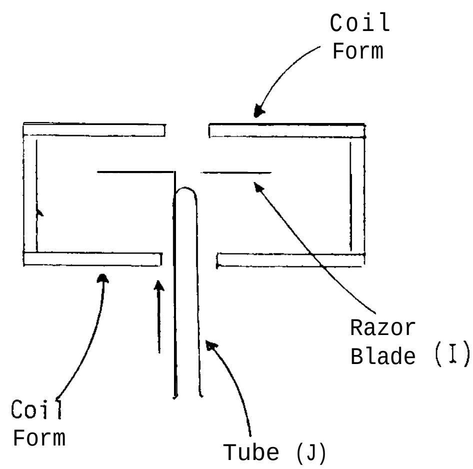


Drill a hole (0.1 cm diameter) in the base in the position that corresponds to center of the larger hole in the base of the coil form. Cut the end (containing the eye) off needle (H) to make it 8 cm long, and set the blunt end of the needle firmly in the hole in the base, so that it stands vertically with the point upwards. A little epoxy resin may be required to hold the needle firmly in the hole.

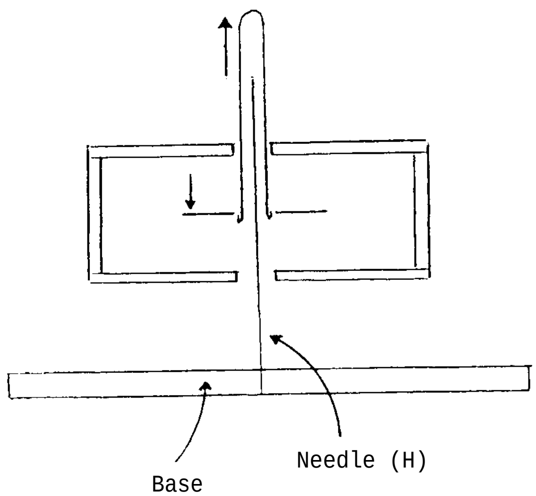




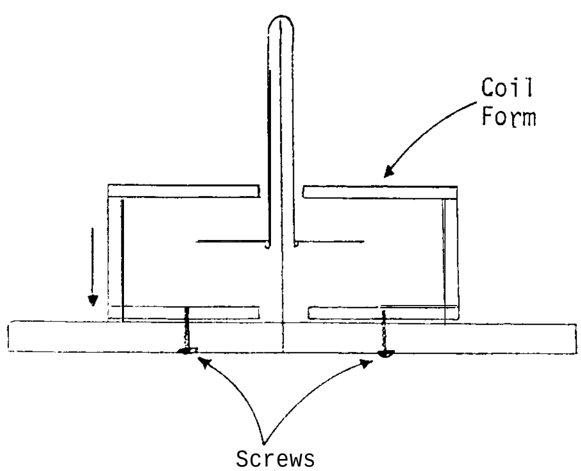
Take a double-edged razor blade (I) which contains a center hole, and magnetize it with the help of a magnetizing coil (IX/Al). Measure the size of the center hole (probably about 0.5 cm diameter), and take a glass tube (J) with the same external diameter as that of the center hole. Heat close (CHEM/I/D5) one end of the tube and create flanges (CHEM/I/D7) at the open end. The flanges on the tube will prevent the razor blade from slipping off the tube, so long as the latter is held in a vertical position.



To put the magnetic needle assembly together, hold the razor blade horizontally inside the coil form. Insert the glass tube through the base hole in the form, and then through the hole in the blade.

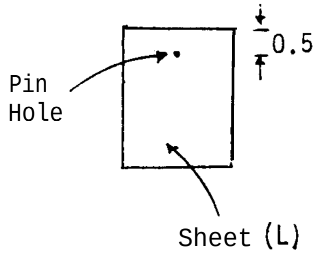


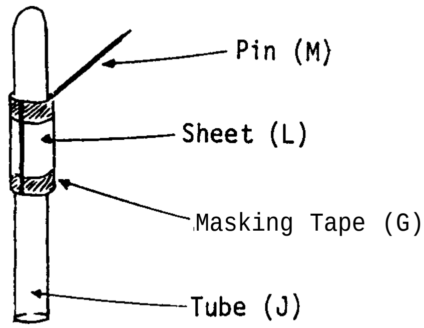
Lower the blade onto the flanges of the glass tube, and raise the tube partially through the upper hole in the form.



Lower the coil form and tube together onto the needle projecting vertically from the base. Take two screws (K) and firmly attach the base and coil form together.

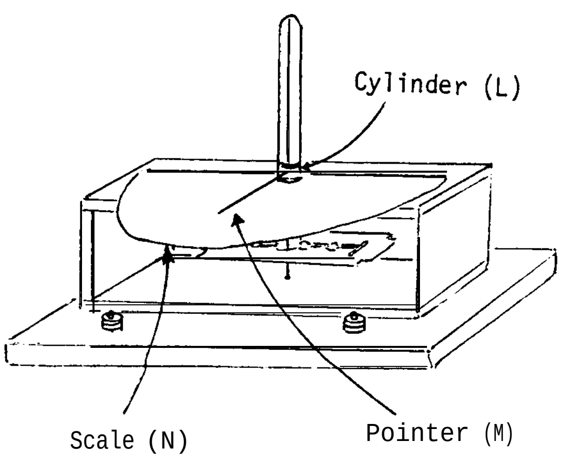
Connect the loose wires from the coils to the terminals, making sure that all enamel has been removed from the wire ends.





Take the thin sheet of cardboard (L), and thrust pin (M) through the sheet at about 0.5 cm from the middle of the top edge. Bend the cardboard around the glass tube (J) to form a tight cylinder from which the full length of the pin will protrude. Fasten the free ends of the cardboard sheet together with masking tape wrapped around the cylindrical sheet.

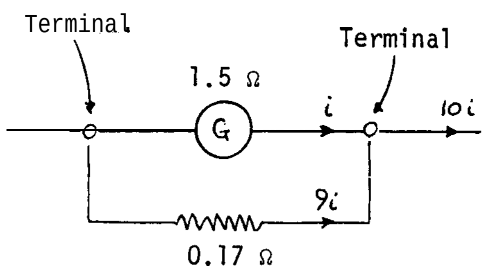
Lower the cardboard cylinder onto the tube until it touches the razor blade. The pin should clear the top of the form by about 0.5 cm, and will serve as a pointer to record the motion of the magnetized needle below.



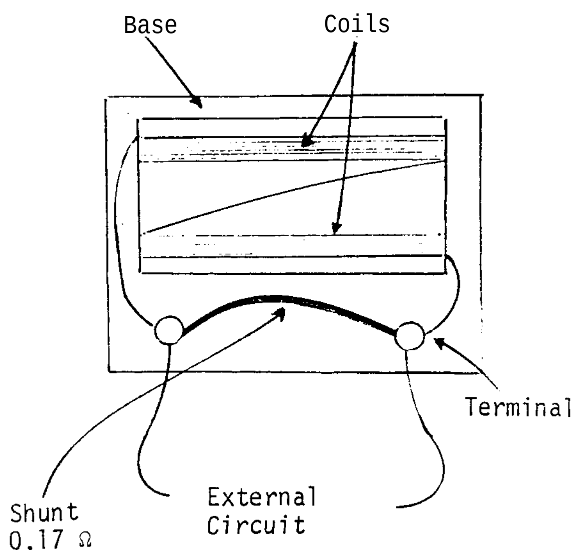
Cut a semicircular disc (diameter B cm) out of the cardboard sheet (N), and set it on top of the coil form to serve as a scale. Mark the position of the cardboard on top of the form, so that the cardboard scale may be replaced in exactly the same position whenever it is removed.

(4) Shunts

Set the plane of the galvanometer coils in a North-South direction so that the longitudinal, horizontal axis of the magnetized razor blade is in the same plane as that of the coils. The direction of the pointer should be set at 90° to this plane. Now calibrate the galvanometer by placing it in series with a milliamneter (0-100 milliamps), a voltage supply (dry cells, battery, etc.) and a variable resistance. The resultant scale will swing from the center zero position of the pointer through about 90°. If the direction of the current through the coil is reversed, a deflection (and hence scale) in the opposite direction will be obtained.

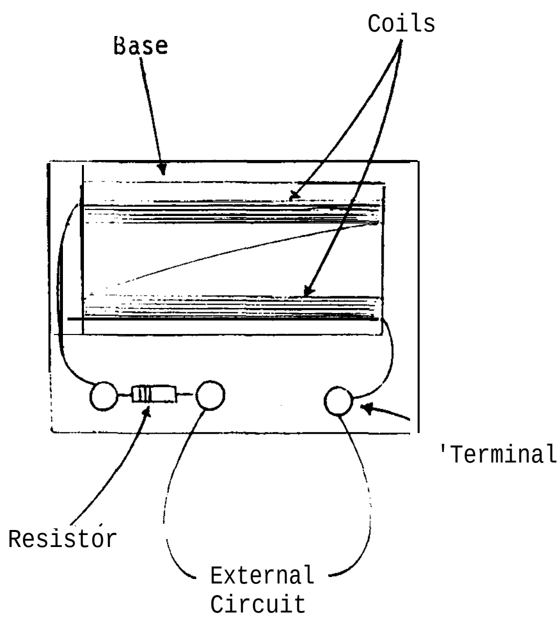


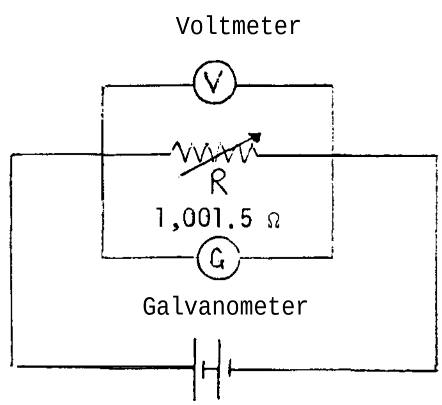
Take a suitable length of nichrome wire (0) and connect it across the galvanometer terminals. In this case, since the resistance of the galvanometer is 1.5 ohms a wire of resistance 0.17 ohms (5 cm of #24, U.S. Standard Plate guage, nichrome wire, 20% chrome, 80% nickel) would result in 1000 milliamps (1 amp) producing a full scale deflection instead of 100 milliamps doing this.



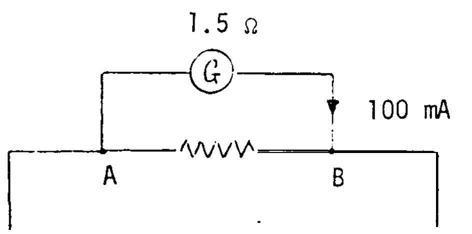
Top View

With the resistance wire across the terminals recalibrate the galvanometer in the usual way with a fresh cardboard sheet for a new scale.

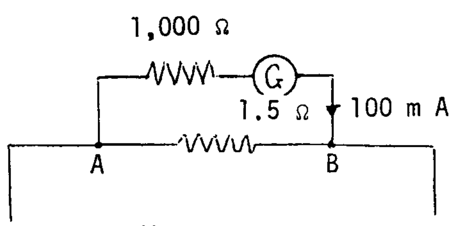




To convert the galvanometer to a voltmeter; add a 1,000 ohm resistor (P) in series to the galvanometer. To do this use bolt (Q) and nut (R) to make a terminal as described under VIII/A2, Component (4), and add it to the base between the existing terminals. Then connect the resistor (obtained from a radio shop) across two adjacent terminals as illustrated. Recalibrate the modified galvanometer by placing it in parallel across a variable resistance, and comparing the potential at any moment with a commercial voltmeter, also placed in parallel with the variable resistance.



V_{AB} = 0.15 volts

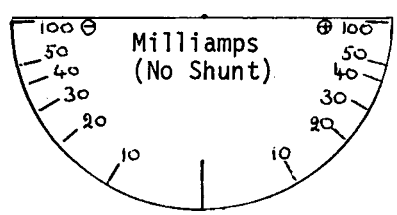


V_{AB} = 100 volts

Without a resistance in series, the full-scale deflection of the galvanometer would only measure 0.15 volts across the terminals. With the 1,000 ohm resistance in series, the full-scale deflection of the galvanometer would measure 100 volts across the terminals, More important, the current taken through the galvanometer, compared with that in the circuit being measured, would be negligible.

C. Notes

(i) The resultant scales will be nonuniform, sensitivity falling off with increasing voltage as indicated. The scale will indicate the direction of the current through the galvanometer.

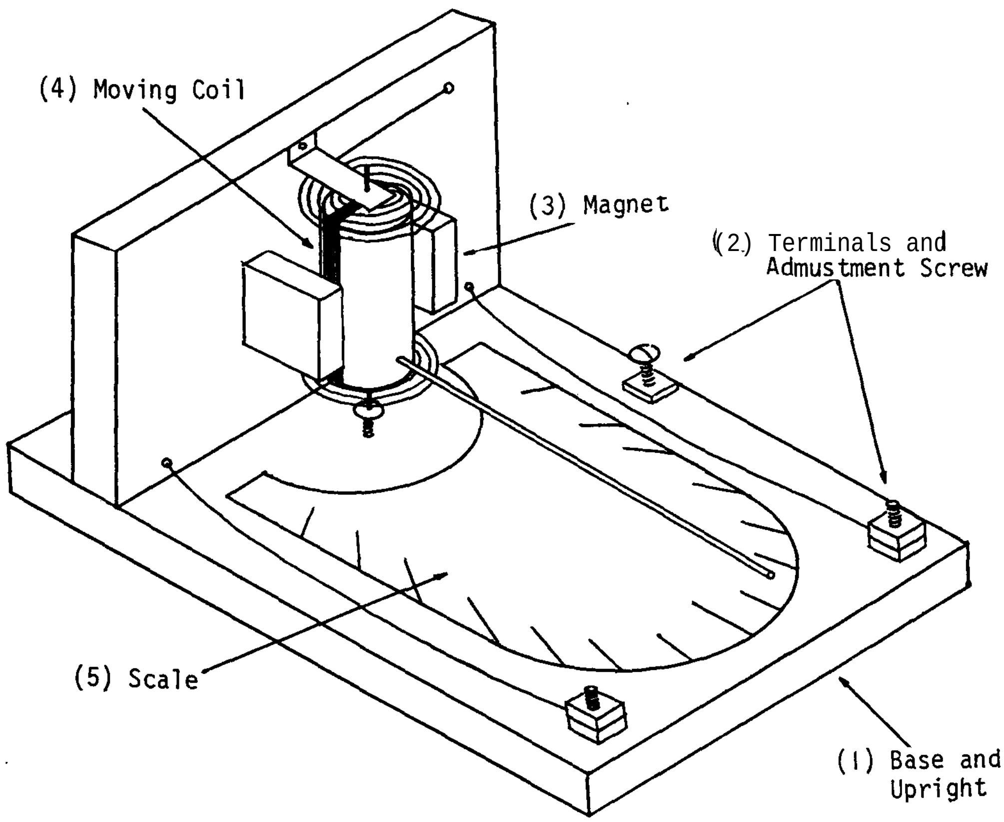


(ii) The galvanometer cannot measure AC current.

(iii) This galvanometer is relatively simple to make, it is surprisingly sensitive, and in combination with the shunts may be used for a wide range of measurements of amperage and voltage.

C. FUNCTIONAL MOVING COIL GALVANOMETERS

Cl. Moving Coil Galvanometer©



a. Materials Required

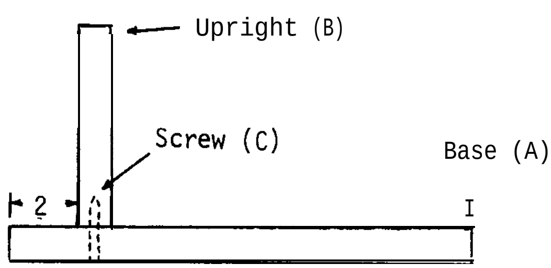
Components	Qu	Items Required	Dimensions
(1) Base with Upright	1	Wood (A)	14 cm x 11 cm x 1 cm
	1	Wood (B)	6 cm x 11 cm x 1 cm
	2	Wood Screws (C)	2 cm long

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for ~~Educational Development Overseas, 1972), pp 153-158.~~

(2) Terminals and Adjustment Screw	2	Brass Bolts (D)	0.3 cm diameter, 2.0 cm long
	4	Nuts (E)	0.3 cm internal diameter
	1	Bolt (F)	0.2 cm diameter, 2 cm long
	1	Nut (G)	0.2 cm internal diameter
	2	Thumbtacks (H)	--
(3) Magnet	1	Horseshoe Magnet (I)	Separation of poles between 3.0 cm and 3.5 cm
(4) Moving Coil	1	Wooden Dowel (J)	2 cm diameter, 3 cm long
	1	Galvanized Wire (K)	7.5 cm long, 0.1 cm diameter
	1	Needle (L)	0.1 cm diameter, 5 cm long
	1	Box of Nails (M)	2 cm long, diameter as small as possible
	1	Roll of Magnet Wire (N)	#22
	2	Pieces of Magnet Wire (O)	#30, 50 cm long
	1	Wood Screw (P)	0.8 cm long
	1	Brass Strip (Q)	3.5 cm x 1.0 cm x 0.05 cm
	1	Wood Screw (R)	0.8 cm long
(5) Scale	1	White Paper (S)	10 cm x 10 cm

b. Construction

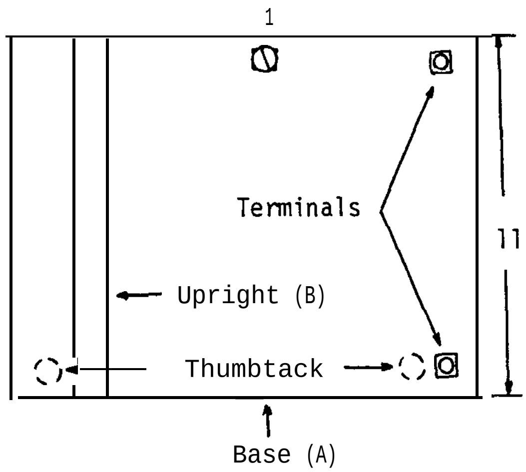
(1) Base with Upright



Side View

Attach the wooden upright (B) to the base (A) with two screws (C) from beneath the base and with wood cement to make a firm joint. Leave approximately 2 cm behind the upright.

(2) Terminals and Adjustment Screw

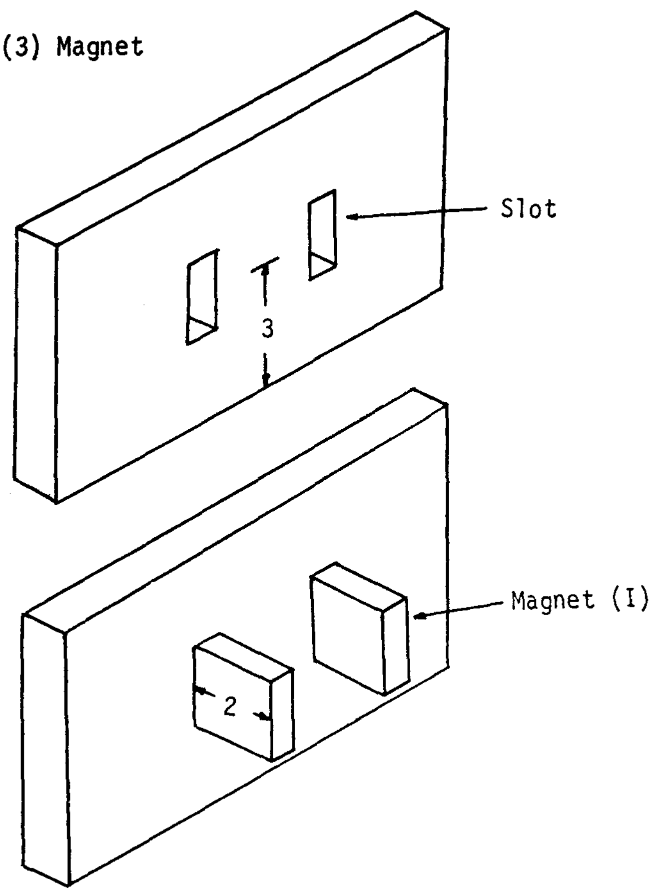


Top View

Make two terminals in the front of the base from the brass bolts (D) and nuts (E) [See VIII/A2, Component (4)].

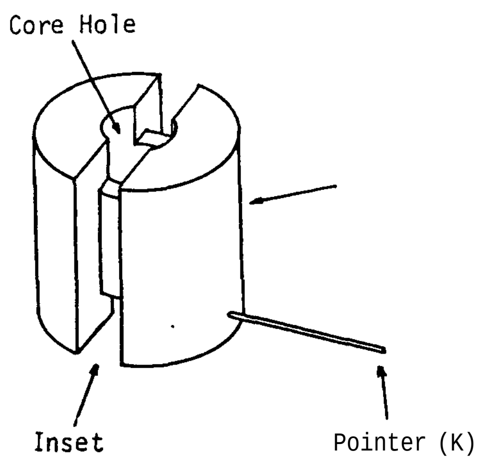
Make an adjustment screw [as described under IX/A3, Component (1)] from the bolt (F) and nut (G) to fit in one side of the base. At opposite corners of the other side of the base, insert two thumbtacks (H) to the bottom so that the base is rested on three points, the adjustment screw and thumbtacks.

(3) Magnet



Obtain a strong horseshoe magnet (I) in which the separation of the two sides of the horseshoe is approximately 3 cm (or a little more). Make slots in the upright (B) as illustrated to allow the magnet to be pushed through the upright so as to protrude a distance of 2 cm. Once the moving coil (below) has been fixed finally in position, fix the magnet firmly in the upright with epoxy resin. The slots are most easily made before the upright has been screwed to the base.

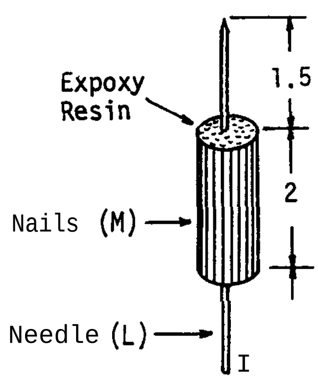
(4) Moving Coil



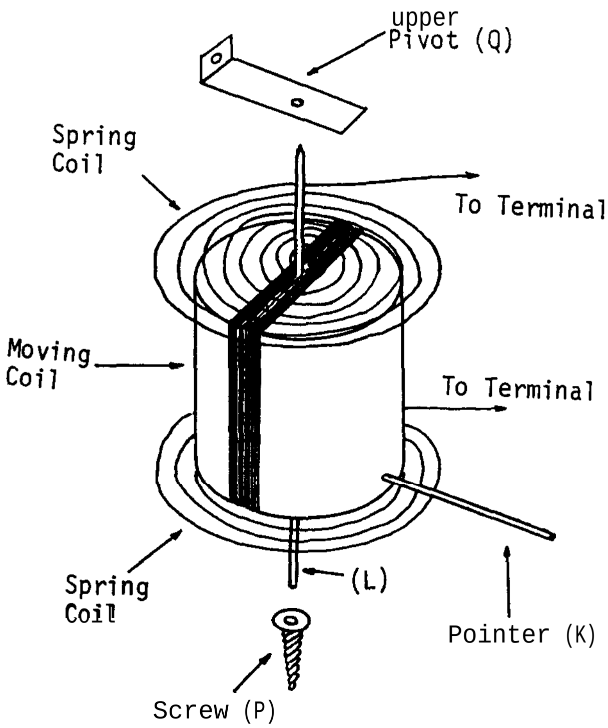
Make an inset (0.5 cm wide, 0.5 cm deep) around the wooden dowel (J) specifically to hold a coil. Drill a hole (0.8 cm diameter) along the axis to take the pivot and soft iron core.

Bore a hole (0.5 cm deep, 0.1 cm diameter) horizontally into the bottom of the core at right angles to the plane of the inset (and coil)

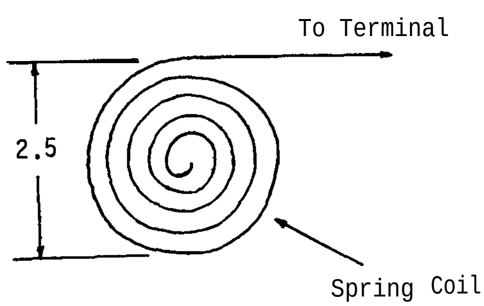
Then, fit the galvanized wire (K) into the hole with epoxy resin to serve as a pointer.



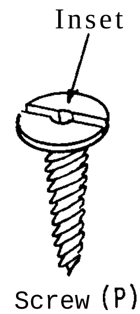
The needle (L) will serve as a pivot. Cut off the heads of the nails (M), and make the length 2 cm. Pack the nails into the hole through the middle of the wooden core (J), placing the needle (L) in the very center of the hole, so as to protrude an equal distance from either end of the core. Bind the newly created core and pivot firmly in position with a liberal coating of epoxy resin over the nail ends and around the needle.



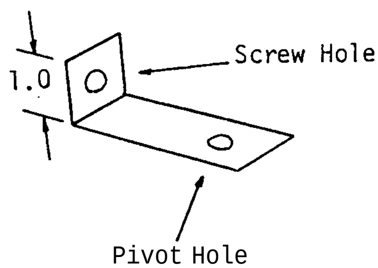
Wind 40 turns of magnet wire (N) around the inset of the core, making sure that both ends are left free. Clean the ends of the wire with sandpaper and solder each end on to another length of very fine magnet wire (0) from which fine spring coils may be made around the top and bottom portions of the pivot.



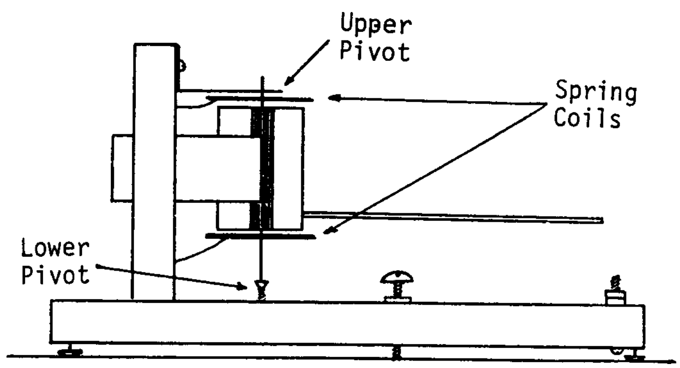
The sensitivity of the spring increases as the number of turns wound into the spring increases, and as the diameter of the spring increases. Once each spring has been wound, avoid subsequent damage during construction by holding it between two pieces of cardboard which may be taped to the wooden core.



Insert the wood screw (P) into the base at a point 2 cm from the front of the upright and centered. Drill an inset (0.2 cm deep) into the head of the screw so that it will serve as a lower pivot for the coil.



Bend the strip of brass (Q) to form an "L" shape. Drill a screw hole (diameter 0.3 cm) in the short end and a pivot hole (diameter 0.2 cm) at a distance of 0.5 cm from the other end. Slide the strip over the pivot needle, and screw the strip to the upright, with the screw (R).



Side View

Connect the wire from the two ends of the springs to the two terminals, One of the best ways of doing this is to drill small holes in the upright (opposite the springs) threading the wire through the holes. If two more holes are drilled through the upright near the bottom (one on either side) the wire may be threaded back through the upright to the terminals.

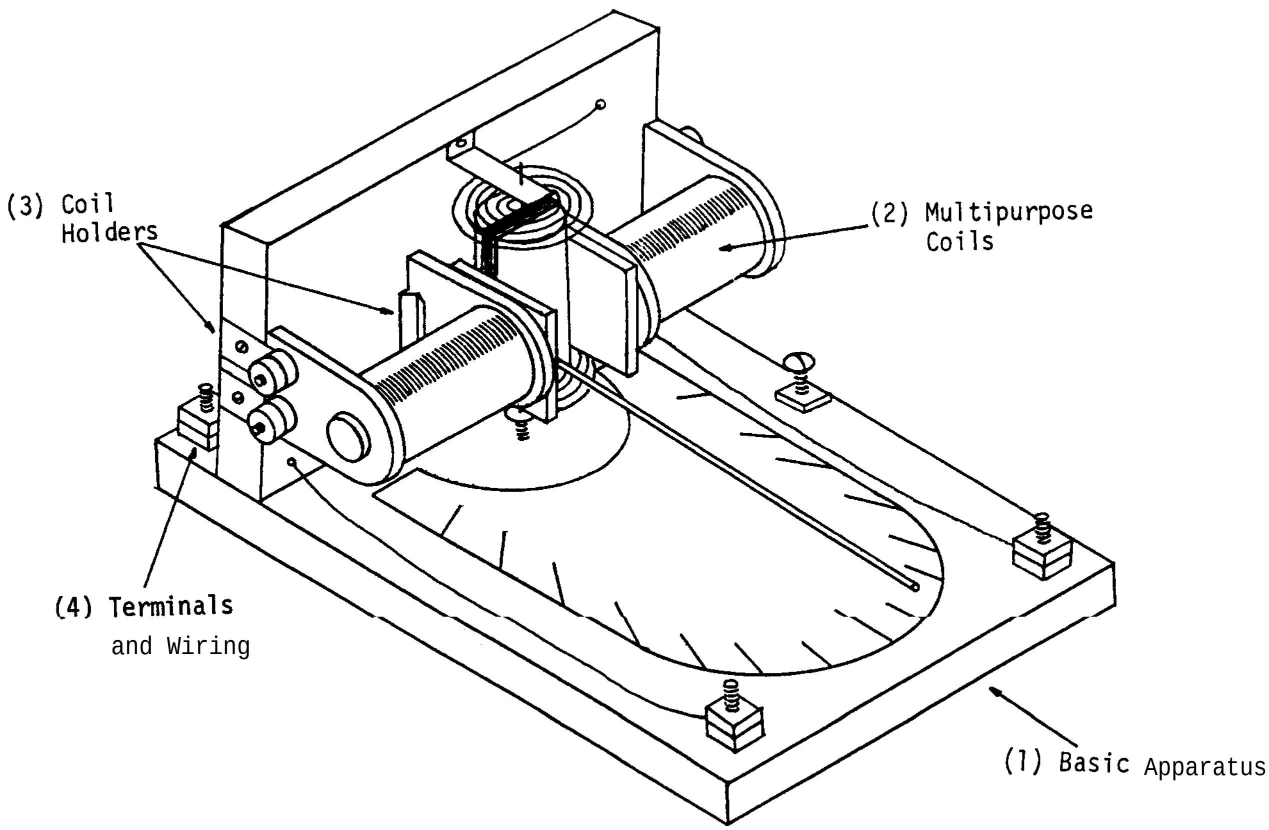
(5) Scale

Cut a sheet of paper (S) and paste it on the base. Taking the lower pivot as the center point, mark off a scale to indicate every 10° movement of the pointer. The scale may later be recalibrated in amps or volts as desired.

c. Notes

(i) Should there be any difficulty in obtaining a suitable, strong horseshoe magnet, then multipurpose coils may be used as described in the next item.

C2. Moving Coil Galvanometer with Multipurpose Coils ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Basic Apparatus	1	Moving Coil	X/Cl, all components except component (3)
(2) Multipurpose Coils	2	Multipurpose Coil with Cores (B)	IX/A2
(3) Coil Holders	4	Brass Sheets (C)	3.0 cm x 0.8 cm x 0.05 cm
	4	Screws (D)	0.8 cm long
	2	Brass Sheets (E)	2 cm x 2 cm x 0.02 cm
	4	Screws (F)	0.8 cm long

© From Reginald F Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 19/2), pp 159-161.

(4) Terminals and Wiring	2	Brass Bolts (G)	0.3 cm diameter, 2 cm long
	4	Nuts (H)	0.3 cm internal diameter
	1	Roll of Magnet Wire (I)	#24

b, Construction

(1) Basic Apparatus

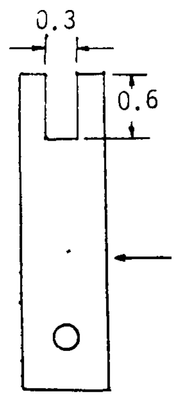
Make the moving coil galvanometer as described under X/Cl, but do not make component (3) of the item or the holes in the upright to take a magnet. The finished product will in fact be the basic apparatus (A).

The subsequent making of the coil holders and addition of further terminals to the basic apparatus is likely to damage the moving coil springs unless these are carefully protected. It is therefore suggested that the springs be held between cardboard sheets taped to the wooden core while further modi-fications are made,

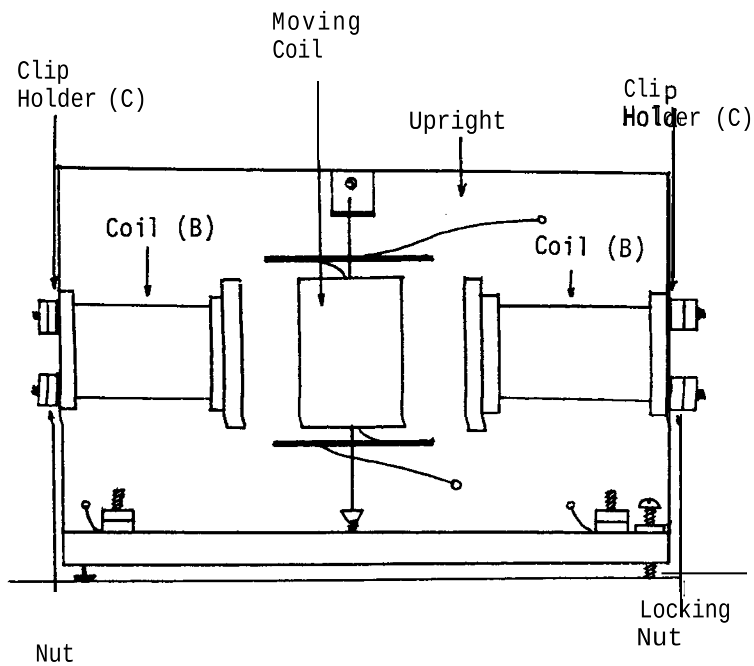
(2) Multipurpose Coils

Make two multipurpose coils (B) complete with soft iron cores and pole heads as described under IX/A2.

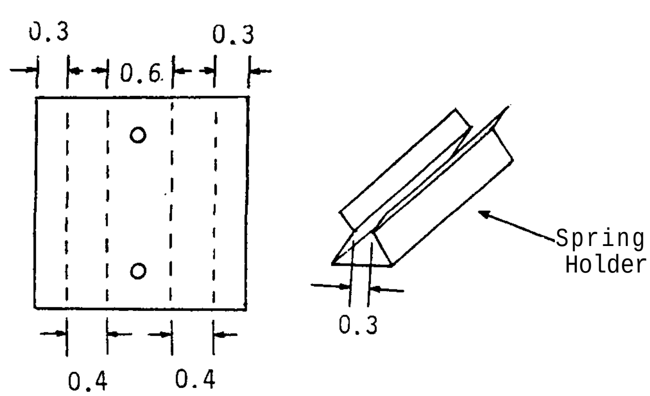
(3) Coil Holders



Cut four clip holders from the four brass sheets (C), making a screw hole at one end and a small slit at the other. Fit the four slits in the holders under the locking nuts of the four terminals of the multipurpose coils (B). Then position each coil in turn on the upright so that the pole head is at exactly the same height above the base as the moving coil core. In this position screw the clips firmly onto the edge of the upright with the screws (D).

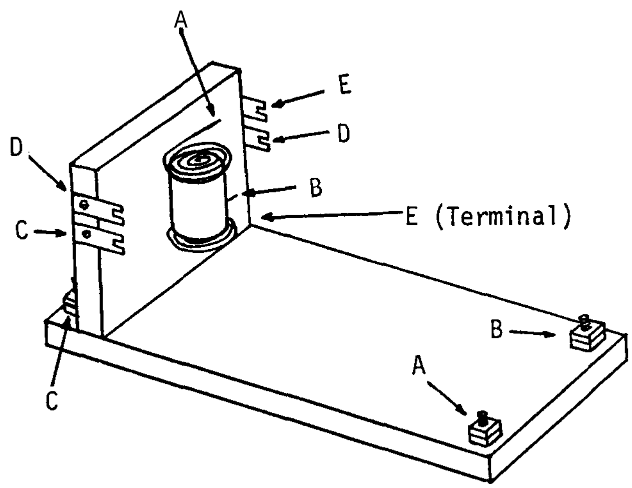


Front View



Make two spring holders from the two brass sheets (E) and slip these on the free ends of the multipurpose coils to determine where they should be attached to the upright. Having marked in the position, screw the holders onto the upright with the remaining screws (F).

(4) Terminals and Wiring



Use the bolts (G) and nuts (H) to make two additional terminals as described under item VIII/A2, component (4). Attach them to the base, just behind the upright, and then connect the clips and terminals with magnet wire (I) so that electrical connections exist between points A to A, B to B, C to C, D to D and E to E, thus insuring that once the additional terminals are connected to a circuit, the resultant current will flow through the two coils in the same direction.

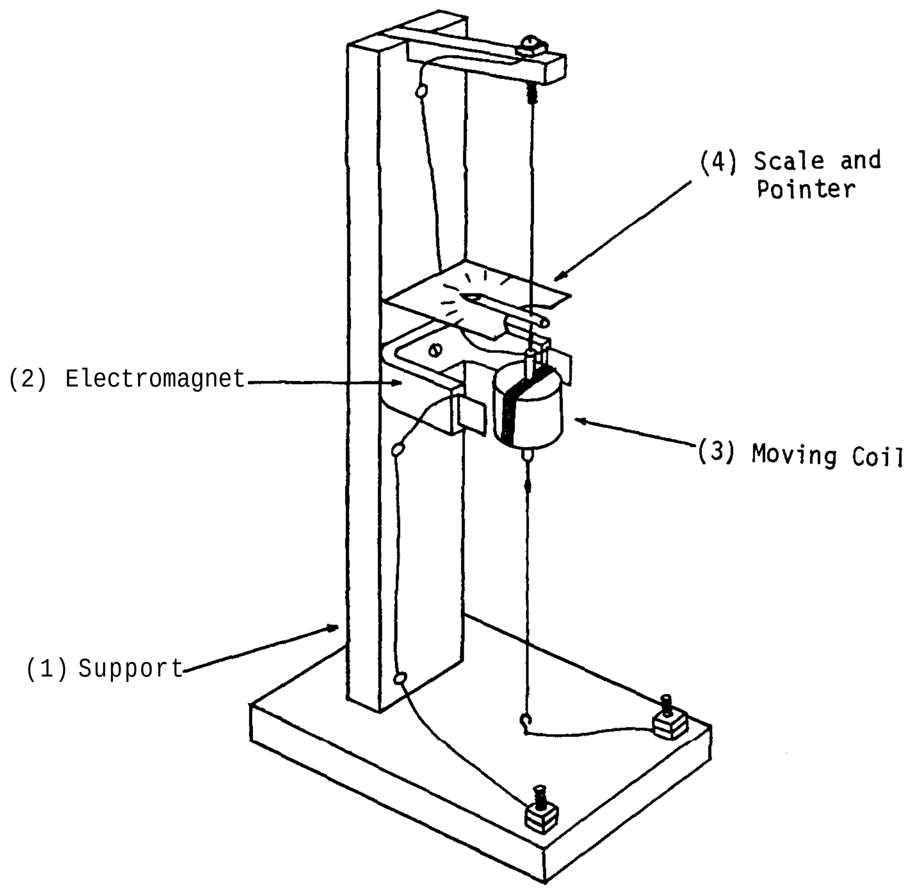
C. Notes

(i) Changing the direction of the current through the moving coil will change the direction of the deflection, so long as the current through the multipurpose coils remains in the same direction. The resultant scale is thus a center zero scale, with the deflection indicating the direction of the current. So long as the current through the moving coil and the multipurpose coils are independent of one another, this galvanometer cannot measure AC current.

(ii) The galvanometer may be calibrated in the usual way by placing it in series with an ammeter (0 → 2 amps), a voltage supple (cells, battery, etc.) and a variable resistance.

(iii) With a current of 0.25 amps flowing through the multipurpose coils, the galvanometer constructed had a range of 0 to ± 1.5 amps. When the current through the multipurpose coils was doubled to 0.50 amps the galvanometer was much more sensitive, and the same deflections produced a range of 0 to ± 0.85 amps.

C3. Moving Coil Galvanometer with Shunts *



a. Materials Required

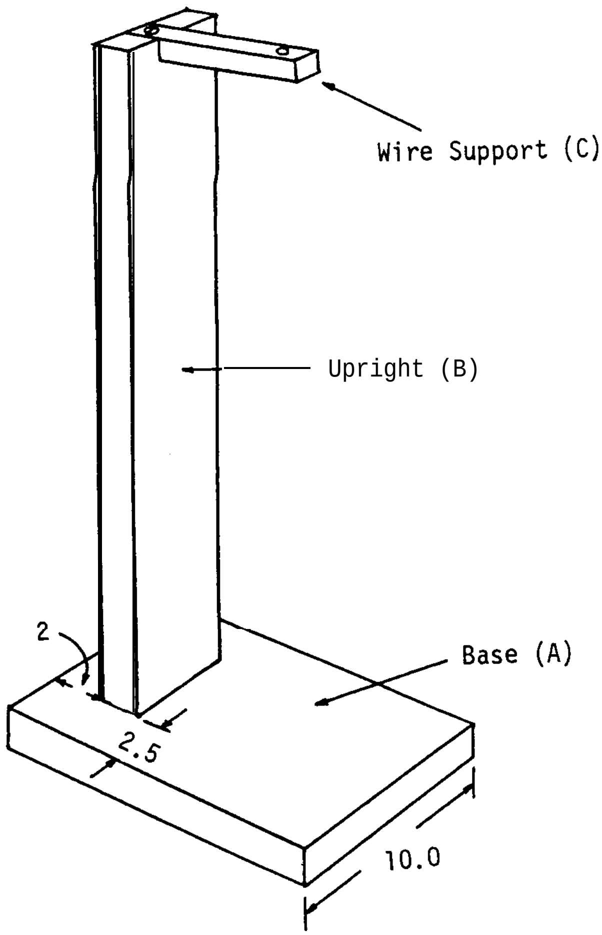
Components	Qu	Items Required	Dimensions
(1)Support	1	Wood (A)	1 cm x 10 cm x 2 cm
	1	Wood (B)	38 cm x 5 cm x 2 cm
	1	Wood (C)	10 cm x 1 cm x 1 cm
	1	Screw (D)	2.0 cm long

*Adapted from Fr. George Schwarz, A Don Bosco Laboratory Manual, (Philippines: Unpublished Papers).

(2) Electromagnet	1	Soft Iron Bar (E)	18 cm x 2.5 cm x 0.3 cm
	--	Masking Tape (F)	--
	1	Bolt (G)	0.3 cm diameter, 4 cm long
	1	Nut (H)	0.3 cm internal diameter
	1	Wing Nut (I)	0.3 cm internal diameter
	1	Magnet Wire (J)	#26 (0.05 cm diameter), 150 g
	1	Bolt (K)	0.4 cm diameter, 3 cm long
	2	Nuts (L)	0.4 cm diameter
	2	Bolts (M)	0.3 cm diameter, 3.5 cm long
	4	Nuts (N)	0.3 cm internal diameter
	4	Thumbtacks (0)	--
(3) Moving Coil	--	Washers (P)	0.6 cm internal diameter, 1.2 cm external diameter
	1	Wooden Dowel (Q)	0.6 cm diameter, 5.5 cm long
	2	Needles (R)	0.1 cm diameter
	1	Wooden Dowel (S)	3.0 cm diameter, 3.5 cm long
	1	Magnet Wire (T)	#26, 800 cm long
	2	Magnet Wire (U)	#30, 16 cm long
	1	Eye Screw (V)	--
	1	Magnet Wire (W)	#26, 7 cm long
(4) Pointer and Scale	1	Soca Straw (X)	5 cm length
	1	Cardboard Sheet (Y)	6 cm x 5 cm

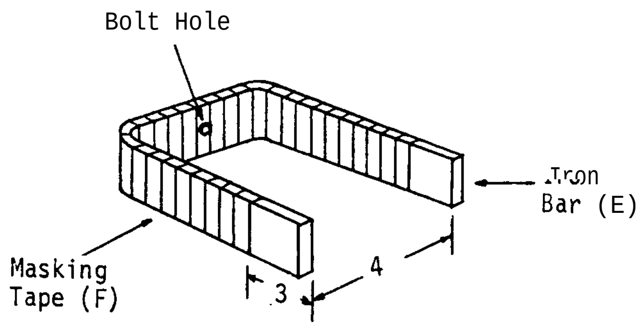
b. Construction

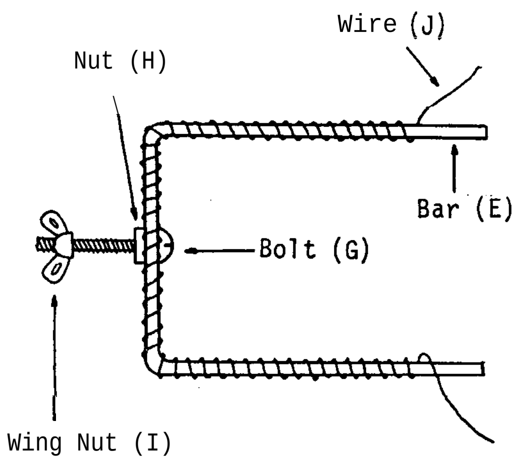
(1)Support

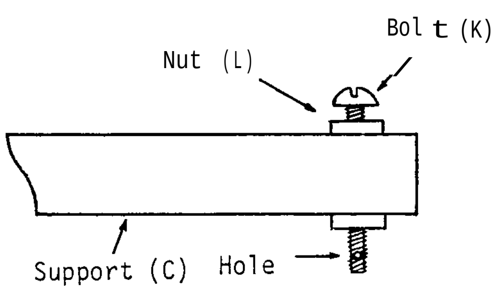


Use wood (A) for the base. Drill two screw holes in the base and attach a wooden upright (B), as indicated, with the help of screws and glue. Make a slot 1 cm wide, and 1 cm deep, in the top of the upright to hold wood (C), the wire support. Drill a hole (0.2 cm diameter) at one end of the support, so that the latter may be attached to the upright by means of a screw, and drill another hole (0.4 cm diameter) at the other end of the support to take a bolt. Attach the wire support to the upright with the help of the screw (D) and glue.

(2) Electromagnet







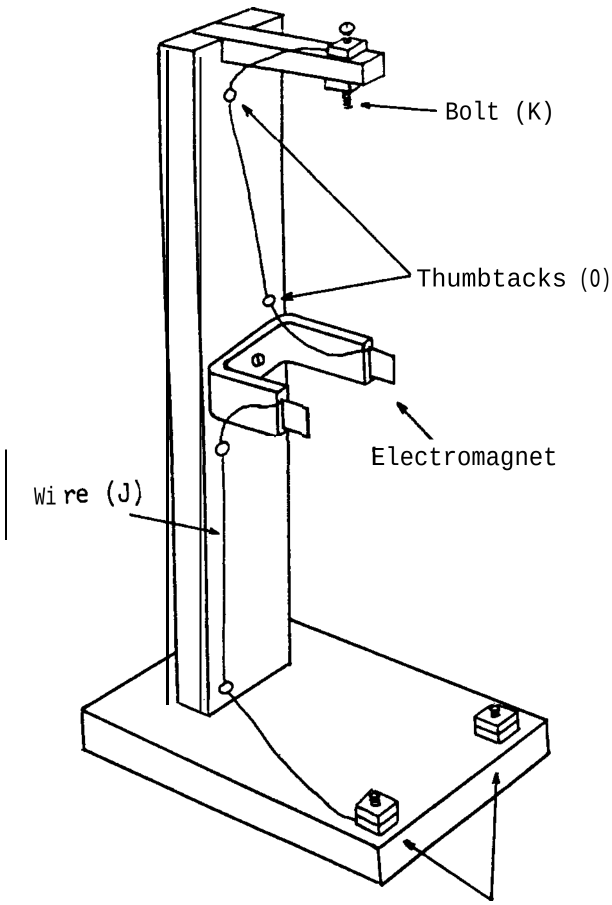
Side View

Bend the soft iron bar (E) into a "U" shape with the parallel sides 4 cm apart.

Wrap a layer of masking tape (F) around the bent bar, leaving the ends (3 cm lengths) clear. The tape will prevent the subsequent magnet wire from being scraped and bared on any sharp edges. Bore a hole (0.3 cm diameter) in the middle of the base of the U-shaped bar. Insert the bolt (G) through the hole, and attach it firmly to the bar with the nut (H). Wrap about 150 g of magnet wire (J) around the covered portion of the bar to make an electromagnet coil. Leave about 40 cm of free wire at either end of the coil. Cover the final layer of magnet wire with masking tape (F) to hold it firmly in position.

Drill a hole (0.3 cm diameter) through the middle of the upright, and attach the newly made electromagnet to the upright with the help of the protruding bolt and wing nut (I).

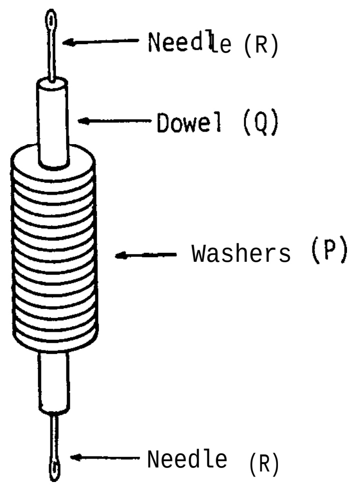
Drill a small hole (0.2 cm diameter) through the end of the bolt (K) furthest from the head. Insert the bolt through the hole in the end of the wire support, and hold it in position with two nuts (L) as illustrated.



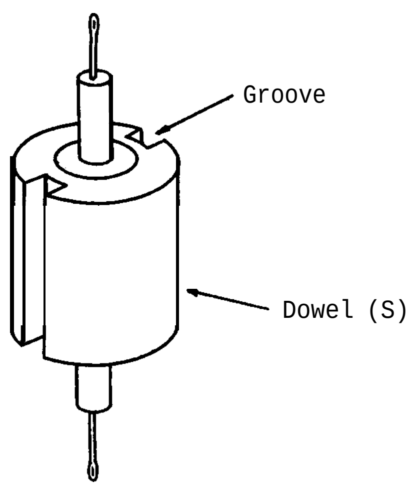
Drill two holes (0.3 cm diameter) into the front of the base. Make two terminals from the nuts (N) and bolts (M) as described under item VIII/A2, component (4). Set the terminals into the holes, making sure they are inset into the bottom of the base, thus leaving the bottom perfectly smooth.

Fasten one of the wires from the electromagnet to a terminal on the base, and the other wire from the electromagnet to the bolt (K) on the wire support. Make sure the enamel has been removed from the wire ends prior to connection. Use thumbtacks (0) to hold the wires in position on the upright.

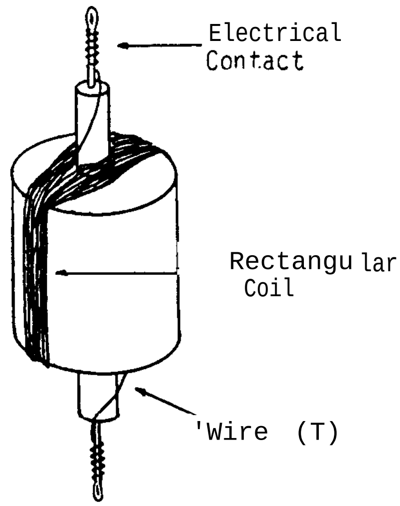
(3) Moving Coil



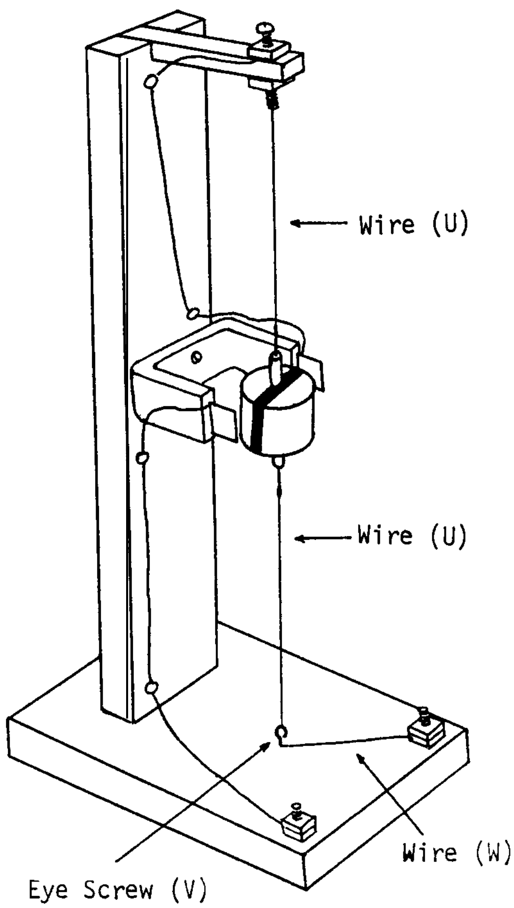
Slide the washers (P) onto the middle of the wooden dowel (Q). Add the washers until they make a stack 3.5 cm long on the middle of the dowel. Use epoxy resin to fix the washers in position. Drill a hole (0.1 cm diameter, 1 cm deep) into either end of the dowel. Cut two 2 cm lengths off the eye ends of the two needles (R), and insert these into the newly drilled holes (needle eyes projecting). Fix them firmly in position with the help of epoxy resin.



Cut a groove (0.5 cm deep, 1 cm wide) around the wooden dowel (S) to hold the subsequent magnet wire coil in position. Drill a hole (1.2 cm diameter) along the axis of the spool, and insert the newly made stack of washers on the dowel (Q). Use epoxy resin to hold this firmly in position within the dowel.



Take the magnet wire (T) and wind it around the dowel (S) to make a rectangular coil contained within the groove which was cut for this purpose. Bare the ends of the wire, and wrap them around the stem of the top and bottom needles (R) respectively, insuring good electrical contact between magnet wire and needle.

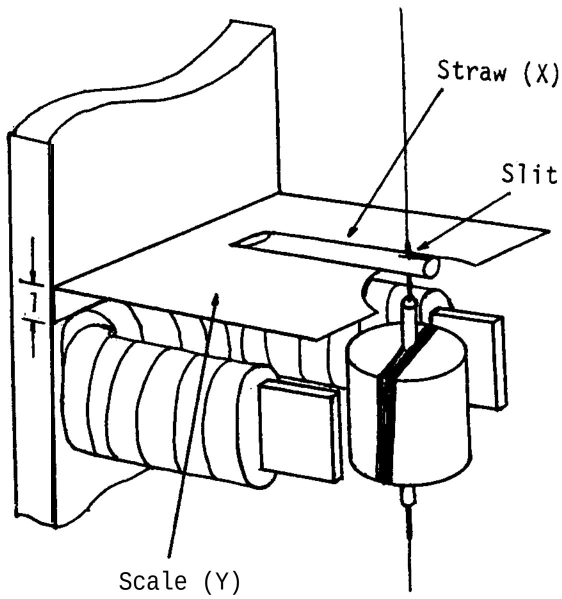


Bare one of the ends of the magnet wire (U) and wrap it around the eye of the needle in the top end of the dowel (S). Suspend the dowel and coil by the wire, so that the dowel hangs between the pole ends of the electromagnet. With the dowel in this position, fasten the other end of the magnet wire to the hole in the bolt in the wire support (after cleaning the end of the magnet wire).

Take the second length of magnet wire (U) and attach one end (after cleaning) to the eye of th needle in the bottom of the dowel (S). Insert an eye screw (V) in the base, directly beneath the dowel, and connect the other end of the magnet wire (bared) to the screw. The slack should be taken out of this bottom magnet wire.

Connect the eye screw to the unused terminal in the base by means of the remaining length of magnet wire (W).

(4) Pointer and Scale



A pointer for the galvanometer may be made from a soda straw (X). Make a small slit in the end, and fit it around the eye of the needle at the top of the dowel (S). A little glue will hold it firmly in position.

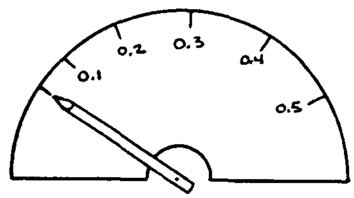
To make the scale, bend the 5 cm end of cardboard (Y) at 90° to make a 1 cm flap, and a flat surface 5 cm x 5 cm. Attach the cardboard to the upright (immediately beneath the pointer) with glue placed between the cardboard flap and the upright.

C. Notes

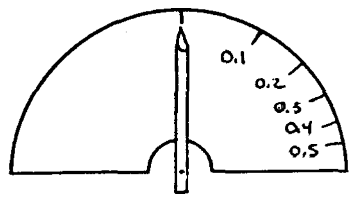
(i) The galvanometer may be calibrated by placing it in series with an ammeter (0 - 1 amp), a voltage supply (dry cells, battery, etc.) and a variable resistance. The resultant scale will not be uniform.

(ii) Changing the direction of the current through the moving coil changes the direction of the current through the electromagnet. As a result, the deflection of the pointer is always in the same direction, regardless of the direction of the current. The galvanometer thus measures AC and DC current equally well. (This would not be the case if a permanent magnet was used instead of the electromagnet.)

(iii) Strictly speaking, the earth's magnetic field should be taken into consideration in using this galvanometer. For most purposes in the secondary school, this confounding factor may be ignored. Hence, in calibrating the galvanometer it is useful to set the zero position of the coil at an angle to the line between the pole heads of the electromagnet, thus making full use of the scale.

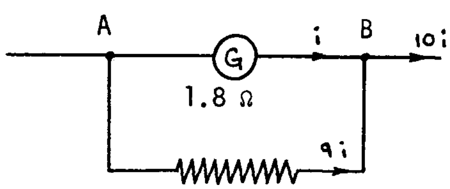


DC Amps

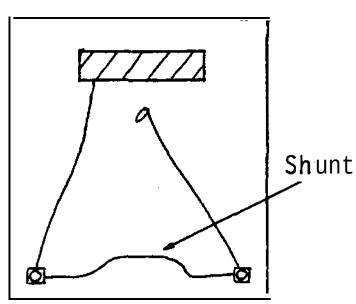


DC Amps

(iv) The resistance of the galvanometer is 1.8 ohms. Hence, if a shunt of 0.2 ohms is placed in parallel with the galvanometer, the scale of the latter will be **multiplied by 10. The full scale deflection will thus correspond to 5 amp instead** of 0.5 amp. Such a shunt may be made from a length of nichrome wire (approximately 5 cm of #24 nichrome, 20% chrome and 80% nickel) connected between the terminals of the galvanometer.

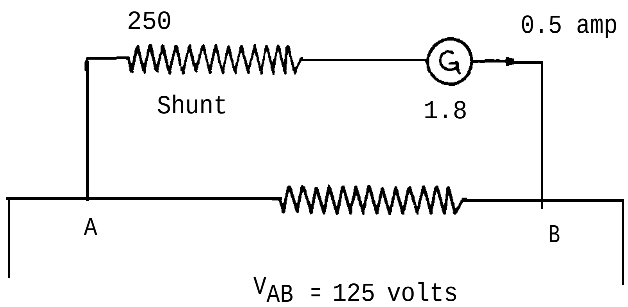


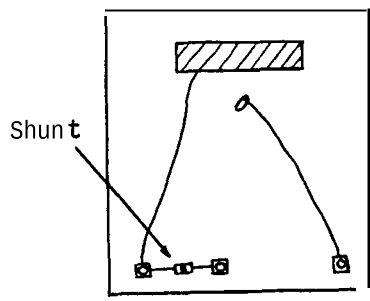
0.2
Shunt



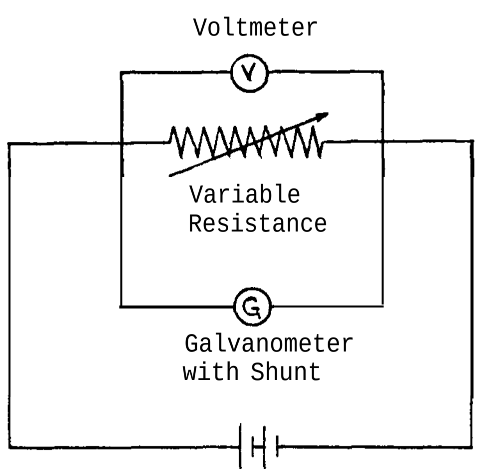
Top View
(Cross-section)

(v) If a 250 ohm shunt is added in series to the galvanometer, it may be used as a voltmeter, the full-scale deflection corresponding to 125 volts (DC). One way of conveniently doing this is to add a third terminal [see VIII/A2, component (4)] to the front of the galvanometer base, simply placing the shunt (obtained from a radio shop) across two adjacent terminals.





Top View
(Cross-section)



The modified galvanometer may then be calibrated by placing it in parallel across a variable resistance, and comparing the potential at any moment with that indicated by a commercial voltmeter, also placed in parallel across the variable resistance.

BIBLIOGRAPHY

A number of texts have proved to be extremely valuable references to the Inexpensive Science Teaching Equipment Project, and these are listed below.

American Peace Corps, Science Teacher's Handbook, (Hyderabad: American Peace Corps, 1968).

This is a clear, well presented book which indicates how apparatus may be constructed for use in biology, chemistry, and physics classes at an introductory level.

The Association for Science Education, Science Master's Book, Part I of Series I to IV, Physics, (London: John Murray).

The material for this series has been selected from the School Science Review, which is published quarterly by the Association for Science Education. It contains details of the construction of many items of equipment, and describes related experiments for use in physics classes at the secondary level.

Association for Science Education, The School Science Review, (London: John Murray).

This is a quarterly journal which describes the construction of apparatus which may be used in the teaching of science at all levels.

Bulman, A.D., Model Making for Young Physicists, (London: John Murray, 1963).

This is a useful book which indicates how students might make some 30 items of physics equipment.

Bulman, A.D., Experiments and Models for Young Physicists, (London: John Murray, 1966).

This publication is on similar lines to the author's book indicated above, and contains descriptions of a further 18 items of equipment.

Joseph, A., P.F. Brandwein, E. Morholt, H. Pollack and J.F. Castka, A Sourcebook for the Physical Sciences, (New York: Harcourt, Brace & World, Inc., 1961).

This book offers not only a wide range of construction ideas, but also a whole series of suggestions for projects and experiments.

Melton, Reginald F., Elementary, Economic Experiments in Physics, (London: Centre for Educational Development Overseas, 1972).

This is a four volume publication which provides not only details of apparatus construction and related experiments, but also provides much detailed information concerning laboratory and workshop facilities. It is intended for use at the secondary level in developing countries.

Merrick, P.D., Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968).

This book and the accompanying materials form a good basis for developing curriculum materials based on the disposable plastic syringe.

Richardson, J.S. and G.P. Cahoon, Methods and Materials for Teaching General and Physical Science, (New York: McGraw-Hill Book Company, Inc., 1951).

This book contains a wide range of ideas for the making of physical science equipment, and includes many related suggestions concerning techniques, skills and procedures.

Strong, C.L., The Scientific American Book of Projects for the Amateur Scientist, (New York: Simon and Schuster, 1960).

The contents of this book are selected from Mr. Stong's clearing house of amateur activities, appearing monthly in Scientific American, and cover a wide range of experiments and related apparatus construction for all fields of science.

United Nations Educational, Scientific and Cultural Organization, UNESCO Source Book for Science Teaching, (Paris: UNESCO, 1962).

This is one of the best resource books available for the construction of simple inexpensive science teaching equipment for use at all levels of teaching.

In addition to the above texts the materials from a large number of projects in the files of the International Clearinghouse on Science and Mathematics Curricular Developments at the University of Maryland have also been particularly valuable. Further details of these projects may be found in:

The Seventh Report of the International Clearinghouse on Science and Mathematics Curricular Developments 1970, (Maryland, U.S.A.: University of Maryland, College Park, 1970).

This is a source of information on curriculum projects throughout the world, and indicates materials available, project directors, publishers, etc. The Eighth Report will be available in late 1972.

ALPHABETICAL INDEX