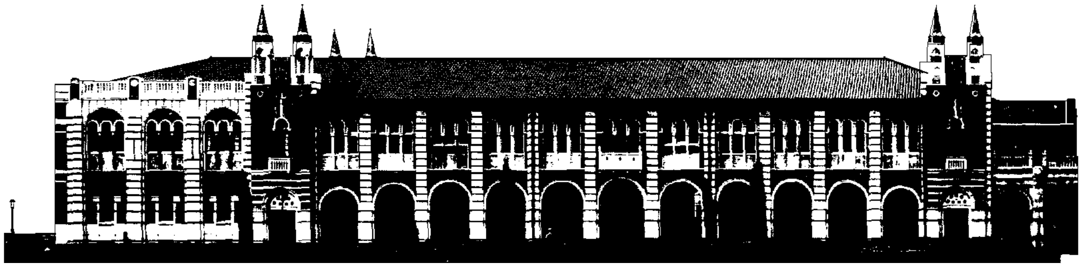

PHYSICS 102

DEMONSTRATIONS

RICE

October 3, 1996

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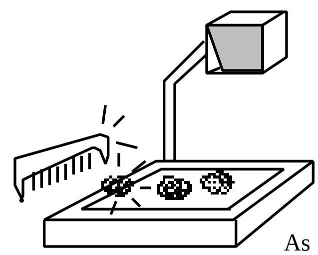
PHYSICS 102 DEMONSTRATIONS:

ELECTRICITY

1. Electrostatics (NOTE: surfaces can be dried by wiping with Methanol.)

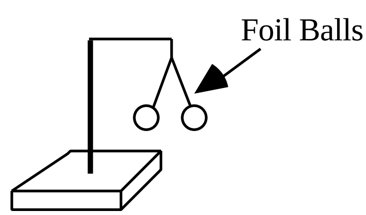
a) Frictional electricity:

1) Run comb through hair or rub plastic with fur. Pick up paper scraps resting on an overhead projector.



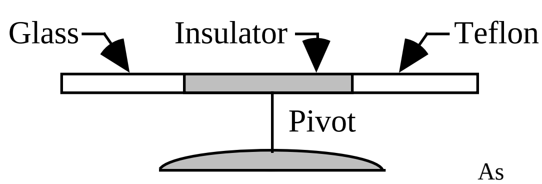
2) Electrify bakelite rod with wool or glass rod with silk. Pick up pith balls as above.

3)



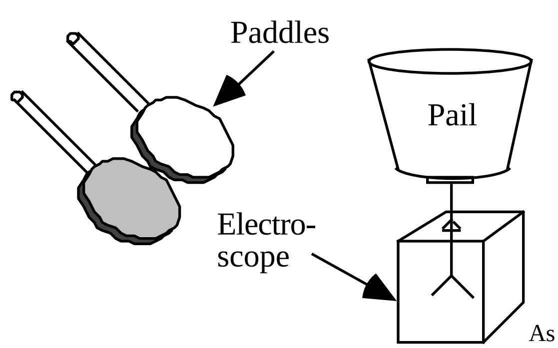
Transfer charge to foil balls on stand. Balls repel. (This may require electrophorus - see part 1g.)

b) + and - electricity.



Mount rod on pivot. Rub ends with wool or silk. Use rods from a) 2. to show that "like" electricity repels, "unlike" attracts.

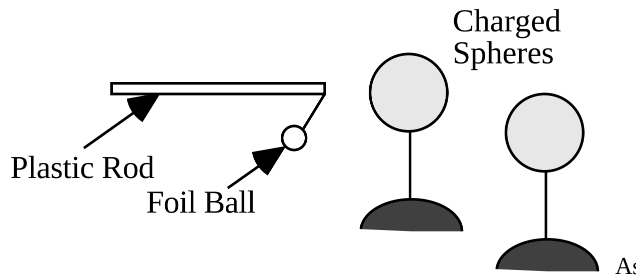
c) Separation of charge: Charge conservation.



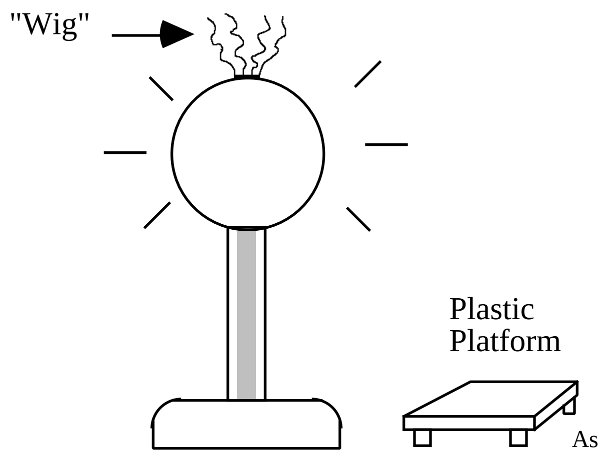
Mount pail on foil electroscope. Rub paddles (one covered with wool) together. Show that each is charged by inserting in pail. Then place both paddles in pail at once. (No deflection!) Or, put paddles in pail when uncharged and rub together while in pail. Remove either paddle to obtain a deflection. [**N**ote: one needs to start with uncharged paddles.] Electroscope can be projected onto front screen.

d) Principle of superposition:

Use foil ball hanging from plastic rod as a "test charge." Show that force on ball is influenced by each of the two charged spheres.



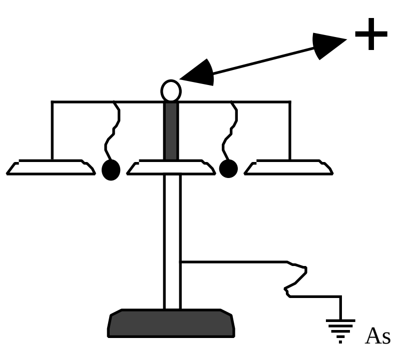
e) Van de Graaff generator:



We have a small Van de Graaff generator to use when large-scale electrification is needed.

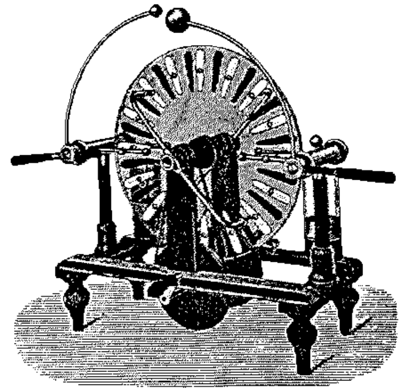
1) There is a small "string wig" that can be attached to the top with wax.
2) Or, have a student with long, dry hair stand on insulating platform. Touch generator with metal rod held in hand.Hair will stand on end on a good cold dry day.
3) You can make a human electro-scope by standing on platform wearing a necktie. (A long piece of string will do.) Touch sphere and necktie will deflect away from chest.

f) Bell-ringer



Top bar, connected to two outside bells, is electrified relative to middle bell, which is grounded. Small metal balls are suspended by threads so that they hang between the bells. They are initially uncharged and will be attracted to outer bells. When they touch the outer bells, they are charged and then repelled toward inner bell. When balls hit middle bell, they are discharged, and cycle repeats. Not a bad door bell! To electrify bells, use the <u>Wimshurst</u> machine.

The Wimshurst Influence Machine



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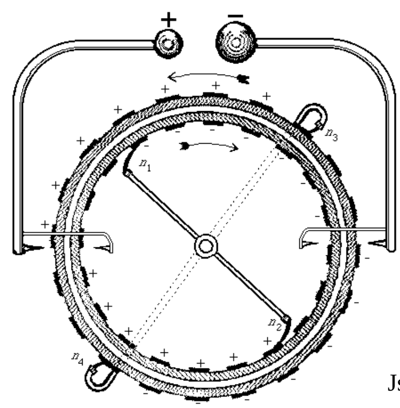
This machine consists of two varnished glass-plates, placed as close togeather as possible, and geared so as to rotate in opposite directions. An even number of metal sectors is fastened on the outer surface of each plate, and these sectors serve both as *inductors* and *carriers.* A conductor with wire brushes at the ends is fixed diagonally on the base board of the machine with their knobs connected to the collecting-combs by movable wires. The action of the machine may be explained by the following diagram of the Wimshurst machine, in which two plates are represented as two concentric cylinders of glass rotating in opposite directions. The neutralising brushes are represented by n_1n_2 and n_3n_4. In order to start the machine it is sufficient if one of the sectors has a slightly different potential from that of the others; as a rule this is the case, and the machine is then *self-starting.* Imagine that one of the back sectors at the top of the diagram has a slight positive charge. When it comes opposite the brush n_1 it will act inductively on the sector touching n_1, giving to it a slight negative charge, and simultaneously giving a positive charge to the sector touching n_2. These sectors, with their induced charges, leave the



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brushes and rotate into positions opposite the brushes n_3 and n_4; the sectors touching n_3 and n_4 will now receive induced positive and negative charges respectively,which they will retain after leaving the brushes. Thus, after one or two revolutions, all sectors approaching the left-hand comb will have a positive charge, and all sectors approaching the right-hand comb will have negative charges. The sectors will be neutralised by the combs, the knobs connected to which will acquire positive and negative charges respectively.

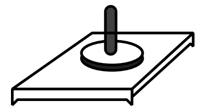
The theory of the Wimshurst Machine , as explained, has been verified by constructing a machine with plates of thin flexible insulating material instead of glass. If the collecting combs are removed, and the plates rotated, the discs will be bent togeather at the top and bottom, and bulge apart at the sides.

The quantity of electricity generated in a given time is proportional to the speed of revolution, but the potential difference between the terminals is independent of speed. An influence machine may be regarded as a source of electric current in which both the potential difference and the internal resistance are very high; with a machine of average size, the potential difference may amount to 50,000 volts, and the internal resistance to 10^9 ohms (the latter varying inversely as the speed).

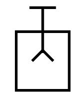
g) Ice-pail experiment.

Basic equipment required:

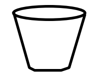
1) Electrophorous -



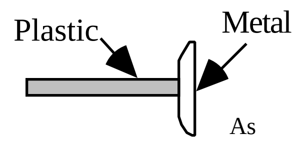
2) Foil electrometer -



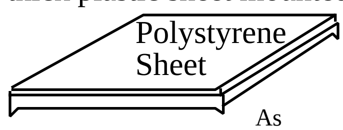
3) Pail -



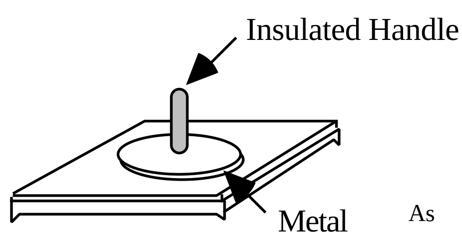
4) "Proof plane" (just a metal disk on an insulated handle) -



The "electrophorus" is a thick plastic sheet mounted on a stand.



If plastic is rubbed with silk cloth, or Kimwipes; it will become charged. Now bring a metal plate into contact with plastic: The metal plate can be charged by induction if you touch top of plate with finger, remove finger, then lift plate from plastic.



The plate is now sufficiently charged to do the ice pail experiment.

(1) The pail is placed on insulating platform and charged from electrophorus.

(2) Show that charge resides on the outer surface by use of proof-plane and electroscope to sample charge on surface.

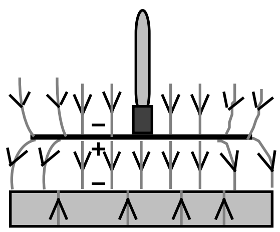
(3) Charge the proof-plane from electrophorus. Insert in pail, but do not touch pail. Remove and show it is still charged. Insert in pail and touch inside surface. Proof will lose all its charge.

(4) Now place pail on electroscope, as in c). Charge pail by induction from electrophorus. Bring up charged proof and show that electroscope deflection decreases, since induction leaves opposite charge on pail. (When proof is placed inside it attracts equal and opposite charge to inside of pail.

(5) Touch proof to inside surface. Charge neutralize, and no further charge occurs at electroscope.

The Electrophorous

This instrument consists of a shallow circular metal vessel filled with sealing-wax or shellac, and a metal disc of about the same diameter with an insulating handle. The sealing-wax is charged negatively by flicking with fur; the metal disc is held over the surface, and is acted upon inductively (Fig.I). In actual practice the disc is laid on the charged surface. The contact is far from perfect, therefore but few points of the shellac are discharged on touching the disc. Also, the strain of the lines of force passing between the table and the charged surface tends to draw the charge within the sheelac, thus preventing its discharge. On touching the disc,the lines of force entering the upper surface vanish (Fig. II); when removed to a distance the disc is positively charged (Fig. IV). The *energy* which becomes evident when a spark is obtained between the charged disc and an earth-connected conductor originates from the mechanical work done in stretching the lines of force when the metal disc is raised.



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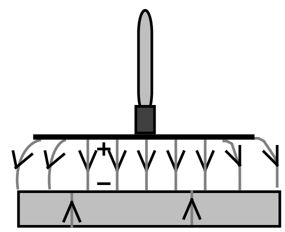
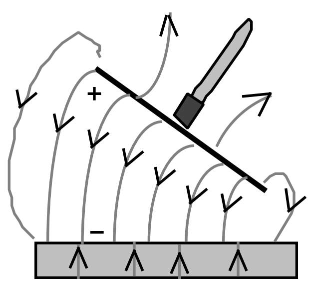
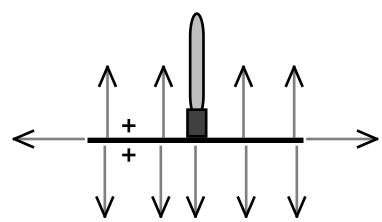


II



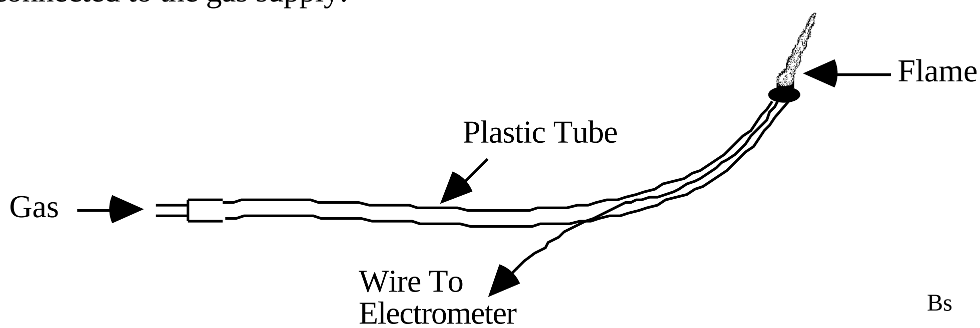
III



IV

2. Electrical Potential

a) V(r) can be measured for the Van de Graaff by use of a "flame probe." To measure V(r) we need a "voltmeter" and a way to make "electrical contact" with the air. For the voltmeter, we use a calibrated foil electroscope (0-1500 volts) which can be projected on front screen. The probe is more difficult. A wire is run through a plastic tube which is connected to the gas supply:

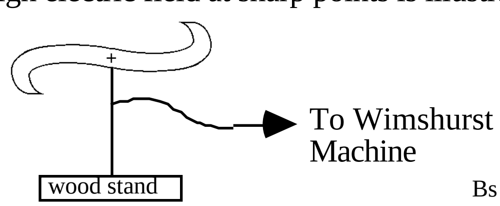


The wire at the end of the tube is in the gas flame, and the free ions will "connect" the wire to the air. You can <u>roughly</u> show that V(r)   1/r with this set-up. [This method can also be used to find V(x) between two parallel plates attached to a high voltage (and high impedance !) supply.]

b) The distribution of charge on a conductor (equipotential) can be investigated with the proof-plane. Charge tends to accumulate at ends and sharp points. This can be illustrated with available rods and egg-shaped conductors.

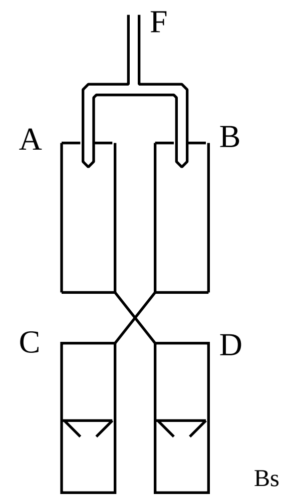
c) We attach strings to a sphere with tacky wax. When sphere is charged, strings will stand perpendicular to surface, along field lines. (Also good for illustrating Gauss's Law.)

d) Electric Windmill: High electric field at sharp points is illustrated by this.



Metal is shaped as shown and balanced on pointed rod in wood stand. When electrified, field at points is large enough to ionize the air. Ions will be repelled from point, and metal will spin as shown.

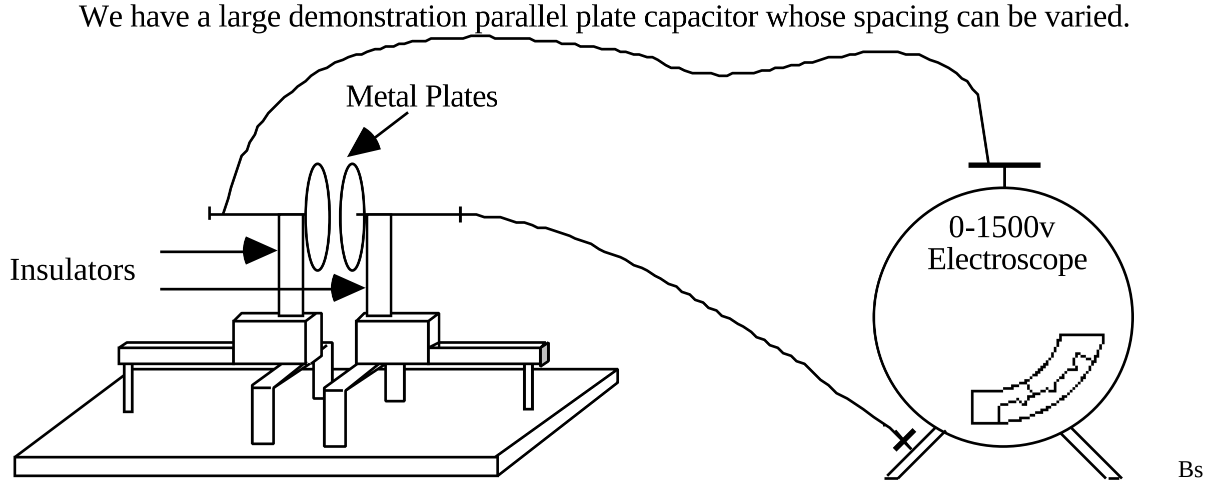
e) Kelvin Generator:
Charging by induction. The principle on which the Wimshurst machine is based is illustrated by this apparatus. We have an apparatus of this form. It can be connected to a projection electroscope, and the build-up of charge due to the falling water drops can be easily observed. Kelvin's water-dropping apparatus is perhaps the simplest arrangement which can be devised to explain the principle upon which all induction machines are based. A, B, C, D are four insulated metal cylinders, of which C and D contain metal cones with narrow openings at the apex. A and D, also B and C, are connected together by wires. F is a T-tube connected to a water-tap; the arms of the T-piece are bent vertically downwards and fixed so that the ends are within the cylinders A and B. *Suppose* A *and* D *to have a very slight positive charge.* A drop of water collecting on the jet within A will, since it is earth-connected, acquire a slight negative charge which it will carry downwards to C when it leaves the jet; C *and* B *thus acquire a slight negative charge.* The drops falling through B will now acquire a positive charge which will be carried downwards and imparted to D. The Charges on A and B will thus mutually augment each other. The charges acquired may be observed by connecting AB and CD to two separate gold-leaf electroscopes. A and B may be termed **Inductors**, also C and D may be termed **Collectors**.



The energy represented by the charges acquired by the cylinders is derived from the kinetic energy of the falling water drops. Owing to the repulsion between the charges on a falling drop and on the cylinder which it is approaching, the velocity of the drop is slightly less than it would be if the cylinders were uncharged, and *the loss of kinetic energy is a measure of the energy of the charge imparted to the cylinder.*

3. Capacitors

We have a large demonstration parallel plate capacitor whose spacing can be varied.



This capacitor can be charged with the electrophorus and the voltage can be measured with the calibrated (0-1500 volt) projection electroscope. Some experiments are:

a) Charge capacitor with plate separation ~ 2 cm and one plate grounded. Study charge distribution (with proof-plane) between both plates, at edges and on outside of plates.

b) Charge capacitor with a moderate plate separation (~ 2 cm). Since V = Q/C, voltage will increase as C is reduced by increasing plate spacing, and will decrease as C is increased (decrease spacing.)

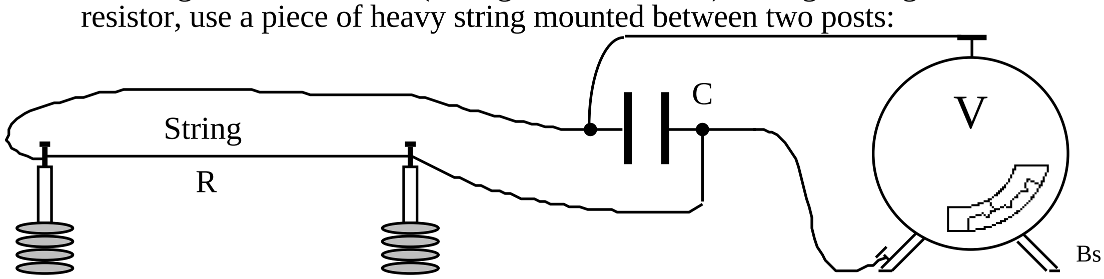
c) Properties of dielectric slab can be studied by inserting clear plastic (Lucite) slab between plates. (Be sure to discharge slab in gas flame before use.) Charge capacitor and show how voltage changes when dielectric is inserted. (Voltage will decrease by the factor K when dielectric is inserted, due to polarization-induced charges on surface of slab.)

You may wish to show various types of capacitors (variable, electrolytic, ceramic, etc.) so that the students will be familiar with them.

4. Currents and Circuits

a) Definition of current: $i = \frac{\Delta Q}{\Delta t}$

Use the demonstration capacitor with the projection electroscope. The capacitor can be discharged at a slow rate (taking a minute or so) through a large resistance. For the resistor, use a piece of heavy string mounted between two posts:



Charge capacitor with electrophorus. The change of voltage with time can be measured: $\frac{\Delta V}{\Delta t}$. Then $i = \frac{\Delta Q}{\Delta t} = C \frac{\Delta V}{\Delta t}$. C can be calculated from the capacitor geometry. The resistance of the string can be varied by "breathing" on it, if humidity is too low to produce a suitable value. Typical values are: string length from 4 to 5 feet and $C = 50610^{-12}$ Farads.

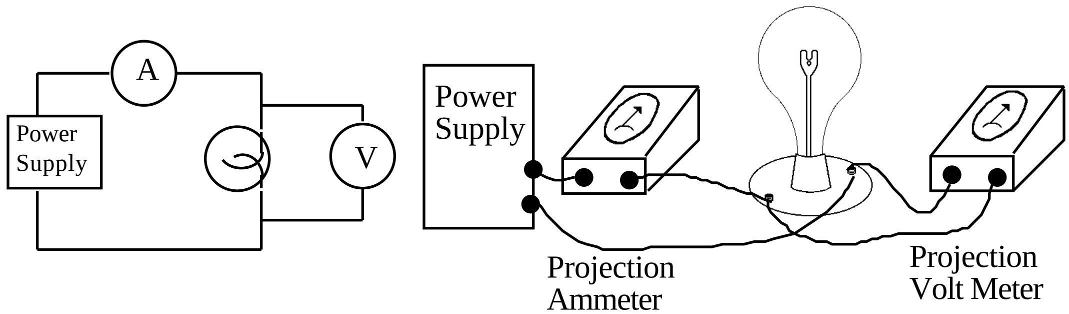
b) Ohm's Law

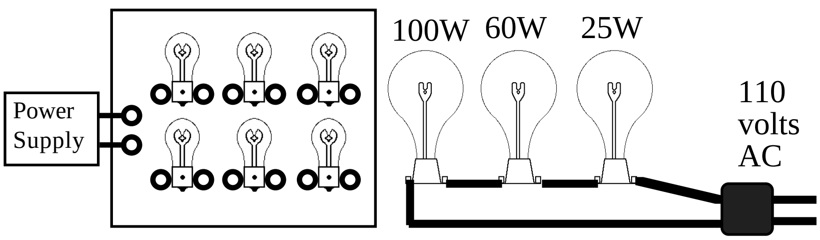
We have two meters with plastic bodies so they can be used with the overhead projector. They are suitable to measure voltages and currents over a wide range with appropriate multipliers.

We also have two D.C. power supplies mounted on a wheeled cart: 155 volts/4 amp; 10 volts/100 amp. Both a 30 volts/20 amp and a 30 volts/5 amp are on the shelf. There are a number of circuit experiments that can be done. Some examples are:

1) Use one of the large wire-wound resistors to determine the V-i curve and show that V is proportional to i.

2) Use a lamp bulb to obtain V-i curve. Show that V is proportional to i only for very small currents. At larger currents (when filament heats up), i becomes less dependent on V. (The resistance is increasing with temperature, so that R depends on i.)



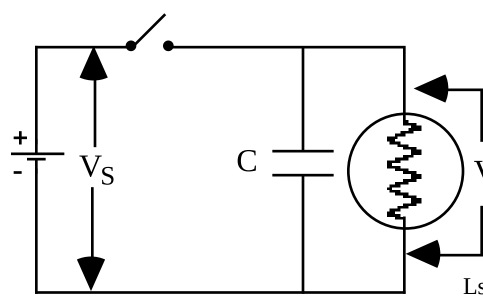


3) Various circuits can be demonstrated (one or two loops) and quantitative measurements of Kirchhoff's Laws shown (loop and node relations). Both 110 volt AC and 6 volt DC fused light bulb arrays are available for demonstration.

[WARNING: 110 volts AC can be hazardous to your health with this set up. Also spectacular fuse blowing can occur when jumpers are misplaced.]

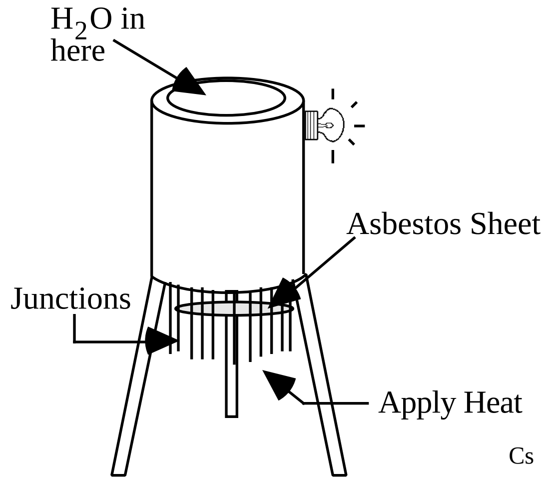
c) R-C Circuits

The exponential decay of voltage across a capacitor during discharge through a resistor can be demonstrated on a scale of a minute or so. Use an electrolytic capacitor of 2000µF and the projection meter on the 10 volt scale to measure the voltage. The meter also provides the resistance. It is 1000 Ω/volt, so that R = 10000 Ω and $\tau = RC =$ 20 seconds. Easiest way to show nature of decay is to show that it always takes the same time for the voltage to drop to half its value, no matter what the starting value. (Start at 10 volts. Measure Δt to reach 5 volts, then to reach 2.5 volts, then to reach 1.25 volts, etc.)

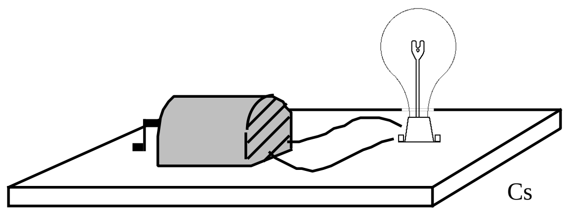


d) Sources of EMF

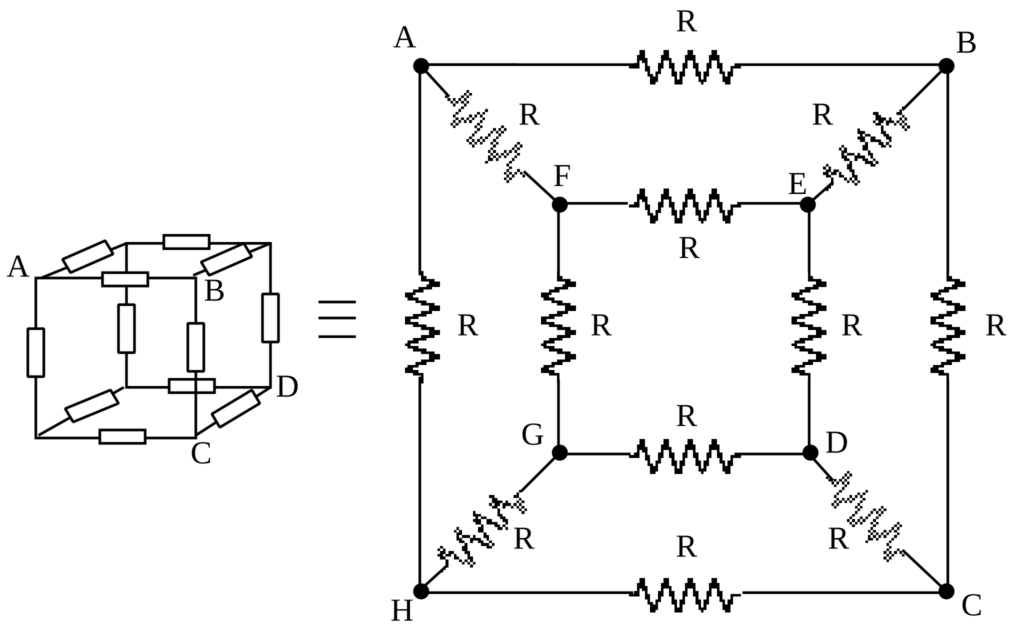
Students are usually familiar with batteries and generators. We have a nice thermo-electric generator. It consists of a large number (~ 100) junctions mounted in a plastic cup. One end of each junction is cooled with water and the other end can be heated with a Bunsen burner. The junctions are all in series with a small flashlight bulb on the side of the cup that will light when the junctions are heated.



We also have a small hand-cranked generator mounted on a base-board with a small light bulb. The intensity of the light depends on the cranking rate. With the light unscrewed, the generator has no load and cranks with little effort. With the bulb connected, the effort required increases noticeably.



e) The Cube: (1000Ω resister on each edge.)



Equal resistors, each R, are arranged on the edge of a cube. Determine the effective resistance:

(a) across an edge (A-B)
(b) across a face diagonal (A-C)
(c) across a body diagonal (A-D)

Brute force method: Assign direction conventions to each edge and associate a current with each edge I_1, I_2, I_3, $\cdots$, I_{12}. Assume a current I_o flows into A and out of B, C, or D; depending on which problem you are trying to solve. Write down loop and junction relationships, solve 12 equations with 12 unknowns.

OR

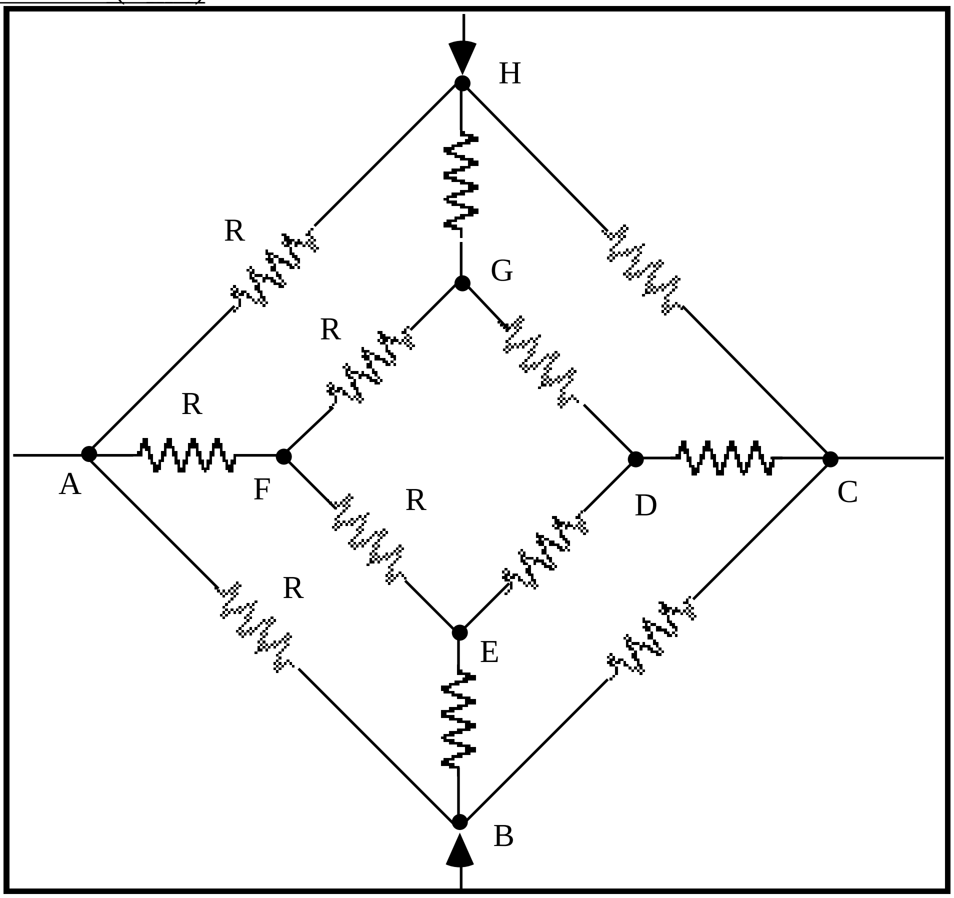
Redraw circuit, note simplifying symmetry. (SEE FOLLOWING PAGES:)

FACE DIAGONAL $\frac{3}{4}$ R = .75 R

BODY DIAGONAL $\frac{5}{6}$ R = .833 R

EDGE $\frac{7}{12}$ R = .583 R

FACE DIAGONAL (A - C)

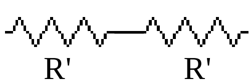


By symmetry:

Every point on line H–B is at same potential; no current flows in vertical resistors.

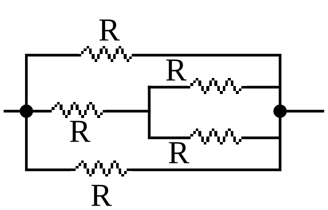
So circuit becomes:

R_{eff} =



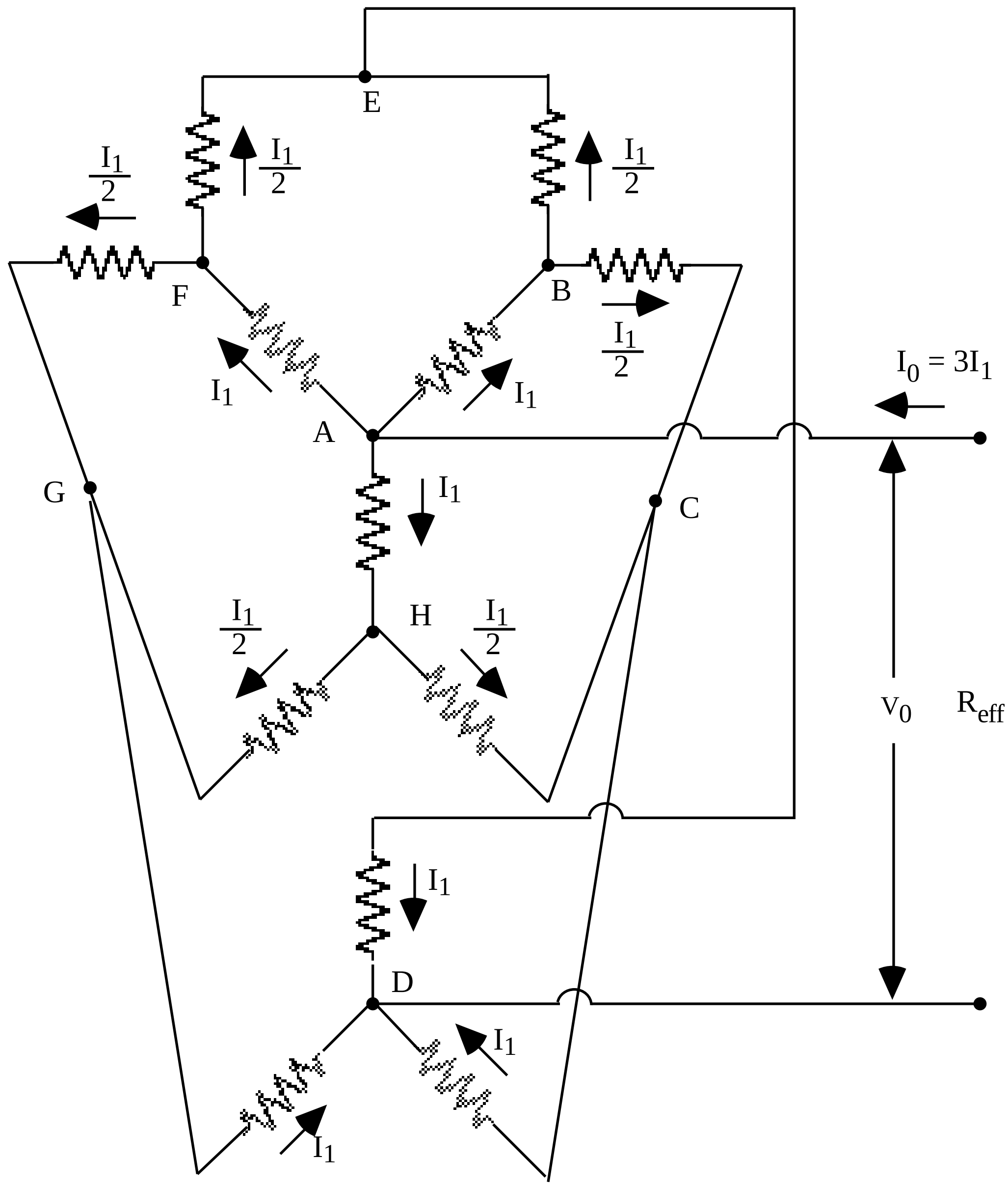
where

R' =



$$R' = \frac{1}{\frac{1}{R} + \frac{1}{R} + \frac{1}{\frac{3}{2}R}} = \frac{3}{8}R \qquad \text{and} \qquad R_{eff} = 2R' = \frac{3}{4}R = .750\,R$$

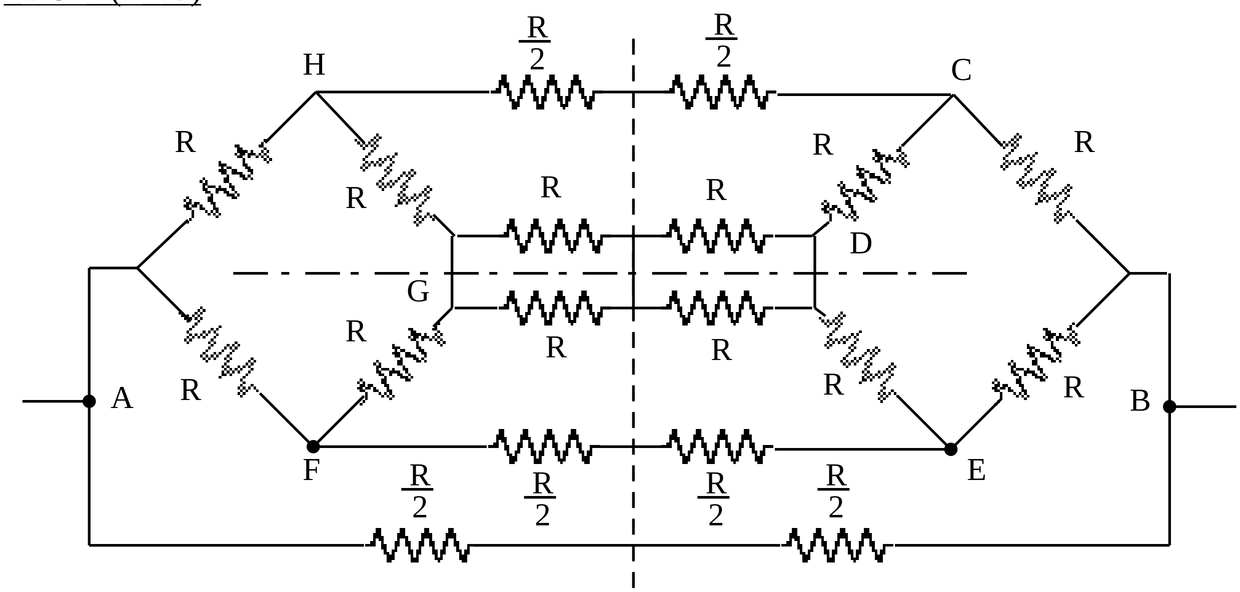
BODY DIAGONAL (A - D)



All resistors are R. Note 3 fold symmetry about A and D. Note that current splits evenly at F, B, and H.

$$R_{eff} = \frac{V_0}{I_0} = \frac{RI_1 + R\frac{I_1}{2} + RI_1}{3I_1} = \frac{5}{6}\ R = .833\ R$$

EDGE (A - B)



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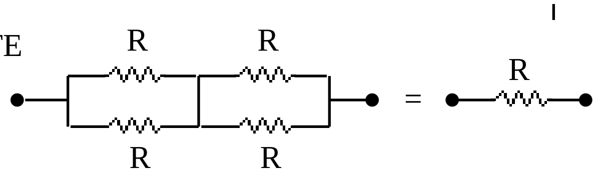
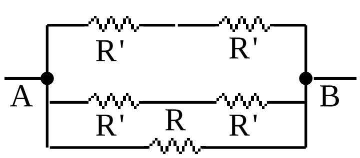


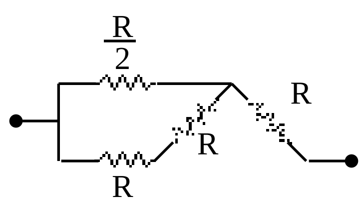
By symmetry:

-> on - - - - - line, equipotential.

-> leads which cross ——— – ——— line, no current, in which case, currents are not affected if we take them away.

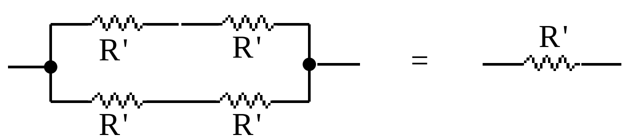
Circuit then becomes:



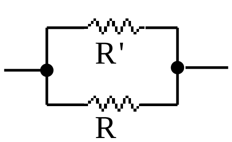
Where R' = 

$$R' = \frac{1}{\frac{1}{\frac{R}{2}} + \frac{1}{2R}} + R = \frac{7}{5} R$$

Now



So



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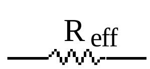
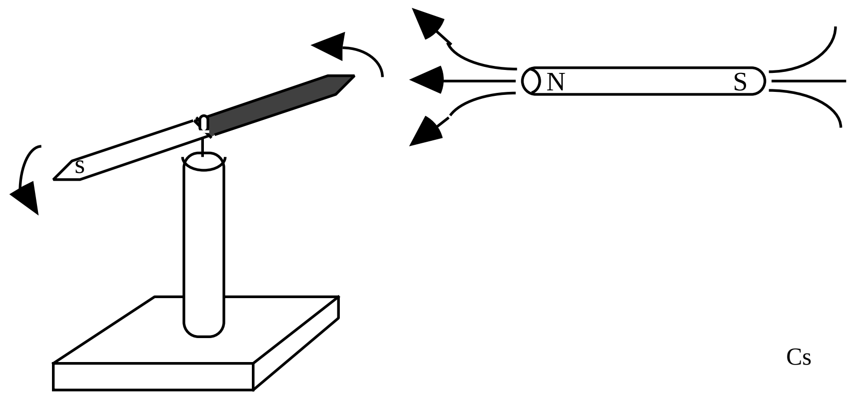


$$R_{eff} = \frac{1}{\frac{1}{R'} + \frac{1}{R}} = \frac{1}{\frac{5}{7R} + \frac{1}{R}} = \frac{7}{12} R = .583 R$$

MAGNETISM

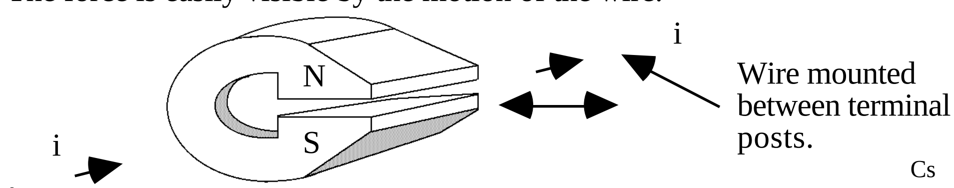
A. Forces

1) "Magnetized" bodies: a source of new forces. We have a large compass needle and several bar magnets with which one can show the forces due to magnetic "poles."

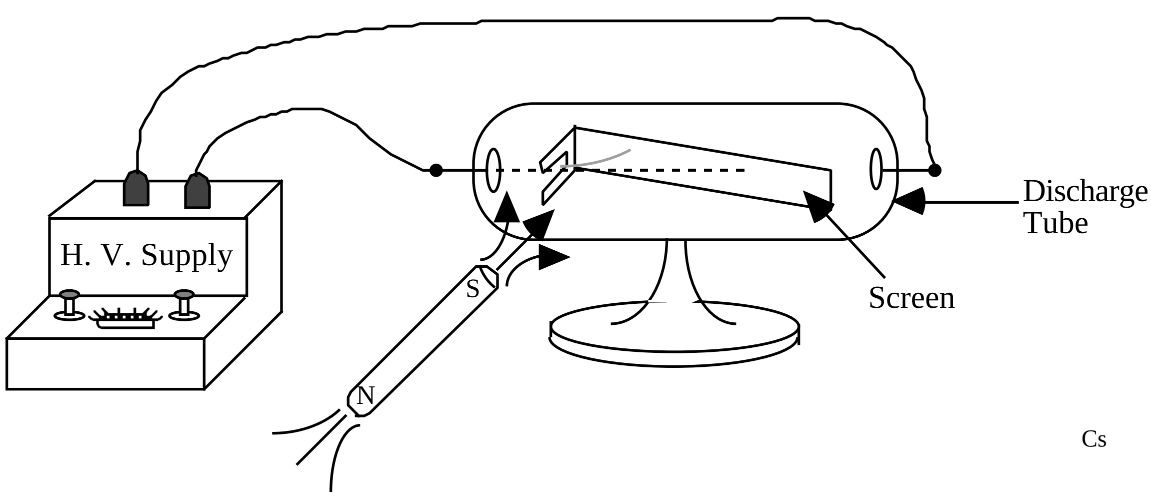


2) Characterization of the magnetic field: force on a current element.

We have a large permanent magnet with a pole separation of ~ 2 cm. This can be placed so that the magnetic field is either horizontal or vertical. A loosely supported wire passing between the poles will experience a side-thrust when a current flows through it. The force is easily visible by the motion of the wire.



3) Deflection of electron beams with a magnetic field.

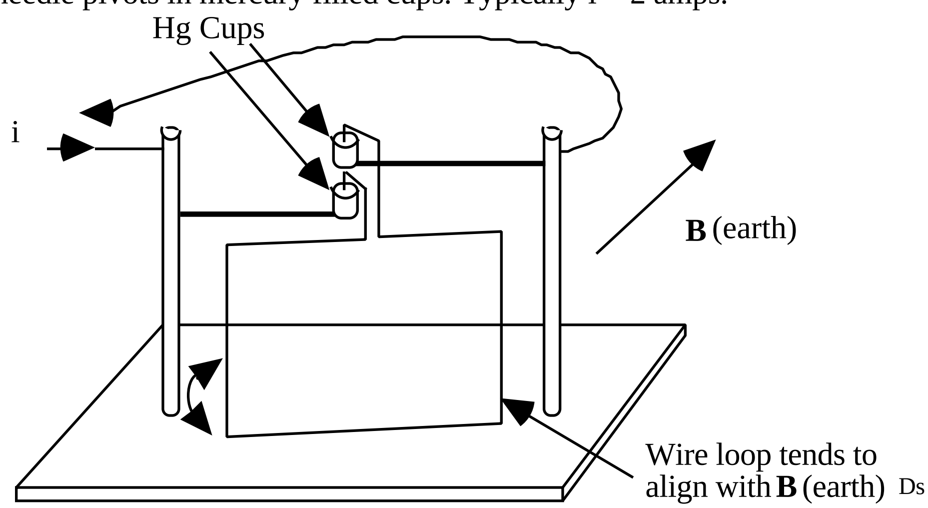


The force on a moving charge can be shown with several discharge tubes that are available. A high-voltage discharge initiated in the tube creates a beam of electrons. The path of the beam is made visible when it strikes a tilted fluorescent screen. The beam can be deflected by bringing a bar magnet up to the beam.

WARNING - Radiation levels of 20 to 40 milliRem/hour were measured 1 meter from the Crooke's tube. The source of the radiation is the emitter (cathode) end of the tube.

4) Torque on a current-loop.

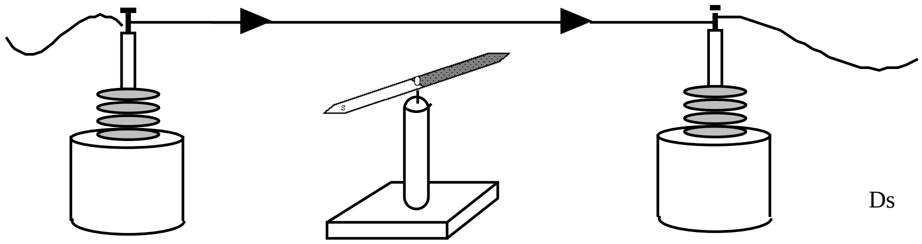
The torque on a suspended loop in the earth's field (or in the field produced by a **large Helmholtz coil)** can be shown with a special suspension system utilizing needle pivots in mercury filled cups. Typically i = 2 amps.



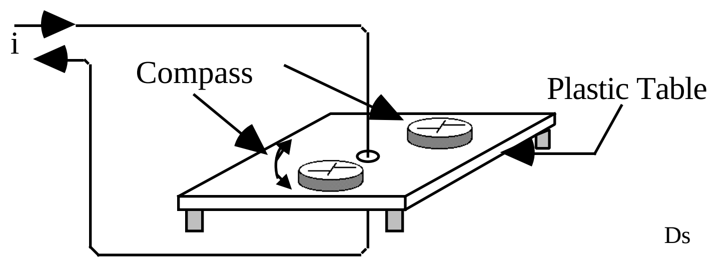
There are several kinds of coils and loops that can be used with this suspension. It is best to attach the current supply to the upper ends of the posts and try to arrange the leads so that the magnetic field due to i is minimized.

B. Sources

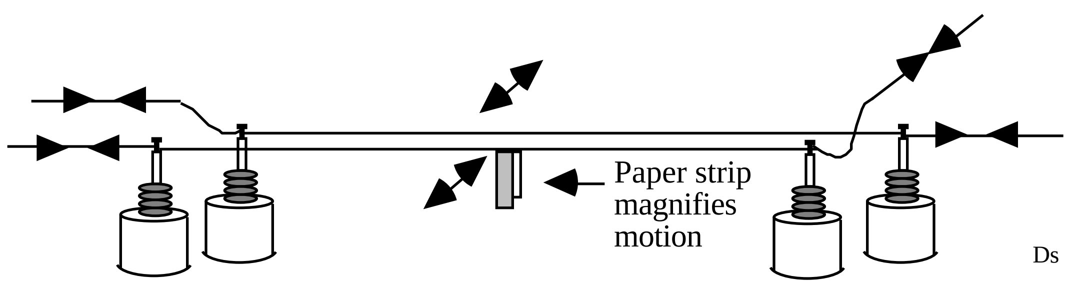
1) The Presence of a magnetic field around a current-carrying wire can be easily shown with a long horizontal wire and the large compass placed with the needle beneath the wire:



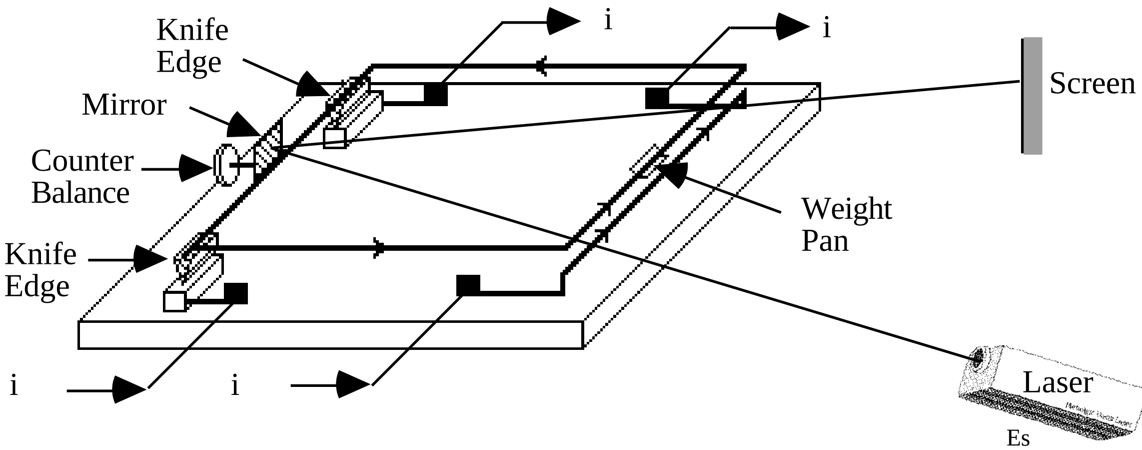
2) A more complete demonstration of this effect uses a vertical current element mounted in a plastic table that can be projected with the overhead projector. The field direction can be shown with a small see-through compass. The decrease of field-strength with distance from the wire can be shown by disturbing the compass needle and observing its frequency of oscillation (Biot-Savart Law).



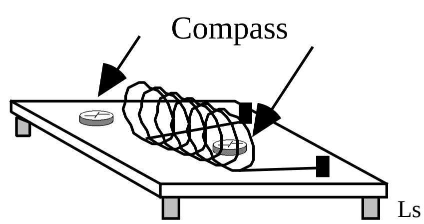
3) The force between two current-carrying wires can be shown by mounting two loosely suspended horizontal wires very close to one another. A large current (~ 20 amps) will produce a weak attraction or repulsion, depending on the direction of the currents. Motion is easily observed if wires are suspended over table of overhead projector.



4) A quantitative measurement of the force between two conductors can be made with a current balance. This apparatus, from CENCO, utilizes a current element suspended on a knife edge and balanced so that the force can be compensated by a small weight. The deflection is observed with deviation of a laser light beam by a mirror on the suspension.



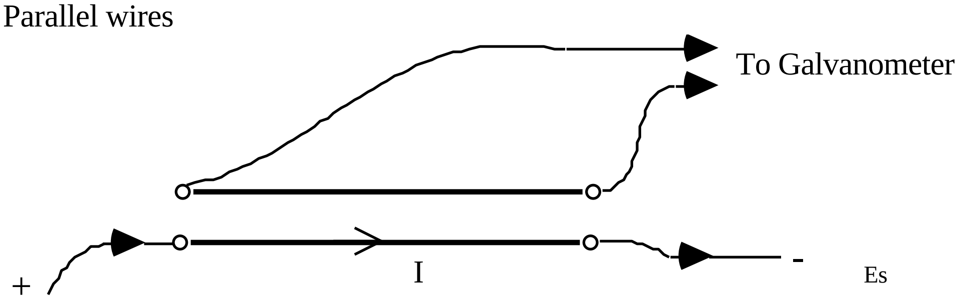
5) We have a solenoid mounted through a plastic sheet, to show magnetic lines of flux with a compass and/or soft iron filings.(**REMEMBER:** put a paper towel around the magnet when picking up the iron fillings.



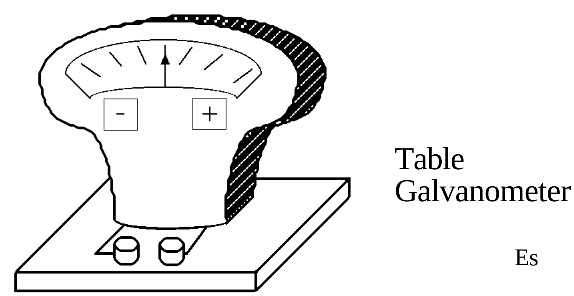
MAGNETIC INDUCTION

1. In electrostatic, we could "induce" a charge on a conductor by bringing a charge nearby. Can we induce a current in a circuit by bringing up a current-carrying wire? There are several ways to study this which "lead" eventually to the idea that it takes a changing current or magnetic field to produce a current.

   a) Parallel wires



Two wires are attached to terminal posts and placed so they are parallel. A current is passed through one and the other attached to a lecture table galvanometer.

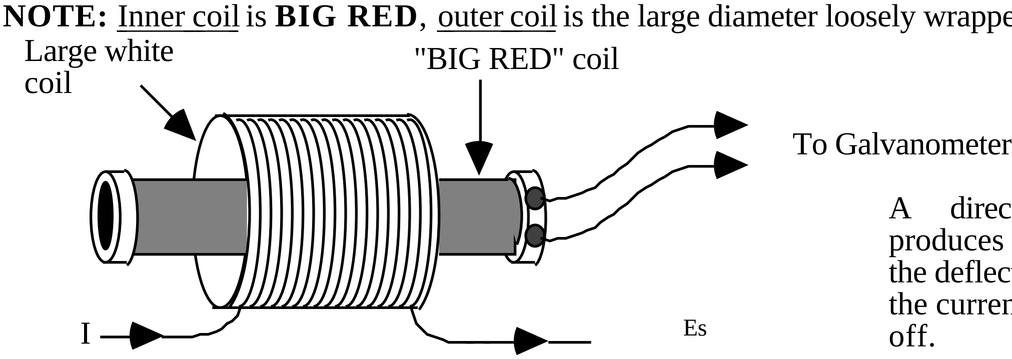


(This is a sensitive center-zero instrument that can be seen by the whole class.) A large current I ≈ 15 amps will produce no visible effect.

   b) Concentric Solenoids

To "magnify" the effect, we increase wire lengths by winding them into coils:

NOTE: Inner coil is **BIG RED**, outer coil is the large diameter loosely wrapped white coil.

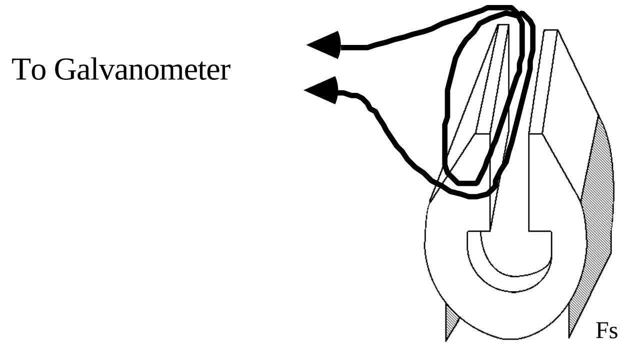


A direct current still produces no deflection, but the deflection appears when the current is turned on and off.

To increase the effect further, put a couple of chemistry stand posts inside of **BIG RED**. Also the current can be passed through **BIG RED** and the 'Galvanometer' attached to the white coil.

2. Magnetic fields. A related question is, since a current produces a B-field, can a B-field produce a current?

    a) Run a wire through the poles of the large permanent magnet and connect to galvanometer. There is no deflection. But when wire is **inserted** or **removed**, a large deflection occurs. Use more than one turn and effect is magnified.

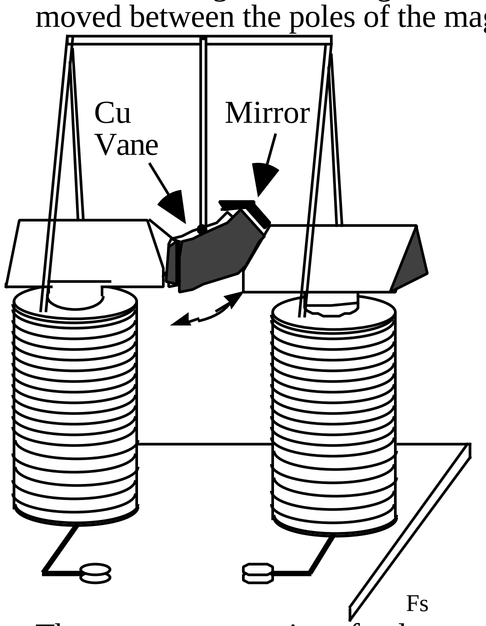


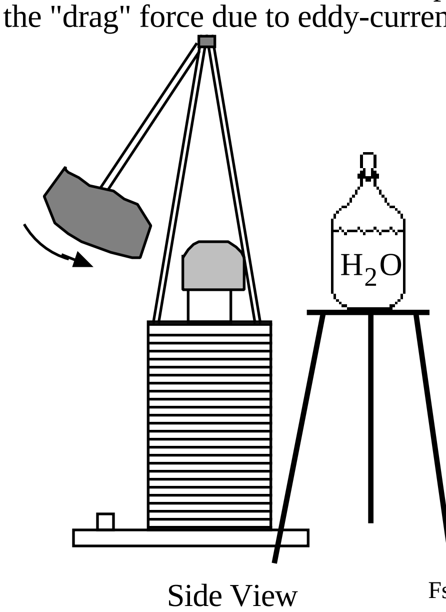
    b) Multiply the effect by a coil with many turns:

    Insert bar magnet, taped to a meter stick, into coil (**BIG RED**); or lower another coil over one pole of the large permanent magnet. There is a large deflection.

3. Eddy-Current damping

    We have a large electromagnet with tapered pole faces for demonstrations. A copper vane moved between the poles of the magnet shows the "drag" force due to eddy-currents.

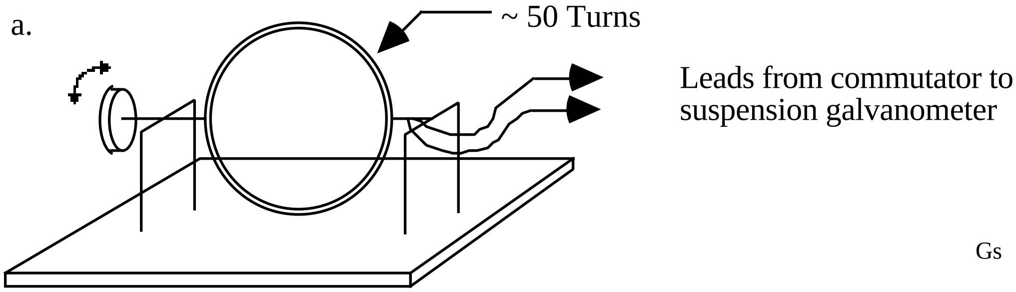




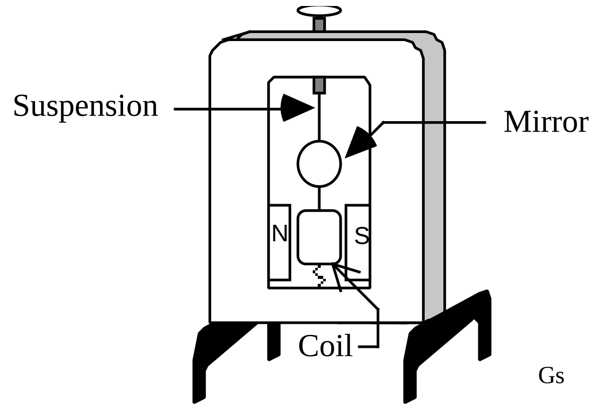
    The copper vane swings freely as a pendulum with no current in the magnet. As the current is increased, the damping increases, and it is easy to reach the highly over-damped case. A dramatic demonstration is to put a bottle of water in a position such that it would be broken by the freely-swinging vane. PUT A MIRROR ON THE END OF THE PENDULUM. Then use a **laser** to show the motion on the wall. (We also have vanes with slots that interrupt the eddy-currents, greatly reducing the damping.)

4. We have a large "earth-inductor" that can be used to show induction from the earth's field.

a.



The table galvanometer is not sensitive enough. Use a **hanging coil galvanometer ->** and reflect laser beam from mirror to show induced EMF.

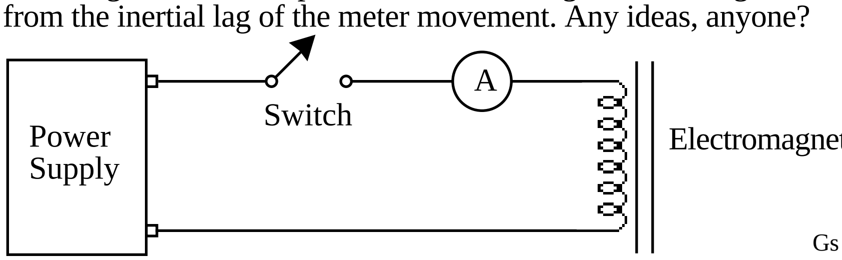


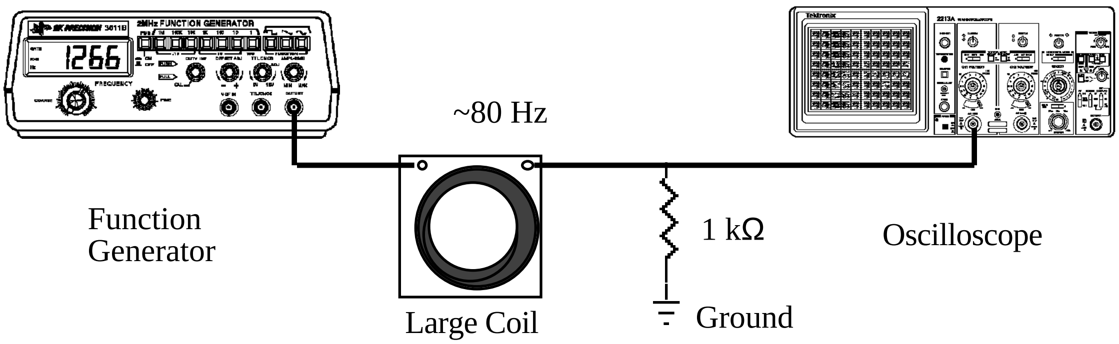
Use the compass and dip-needle to determine the coil orientation for maximum flux linkage. (This system could be used with the Helmholtz coil to produce an effect large enough to be seen on the table galvanometer.)

b. You can also use the TABLE GALVANOMETER, see page 19; if a large horseshoe magenet is placed near the earth inductor at the axis of rotation.

5. R-L Decay

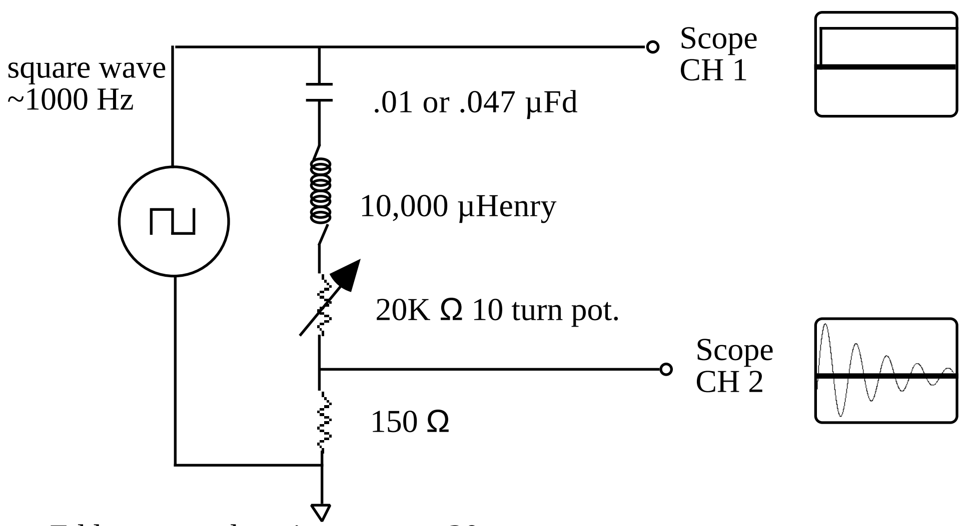
It would be nice to have a demonstration similar to the R-C decay that takes several seconds for the decay. This is not possible without a large superconducting coil for L. One can see a barely visible lag in the build-up of current in the large electro-magnet, but it is only a slight change from the inertial lag of the meter movement. Any ideas, anyone?





With a square-wave output from the function generator, the decay can be observed on the scope, across the resistor. Also insert iron or aluminum into the coil a see changes in display.

6. RLC

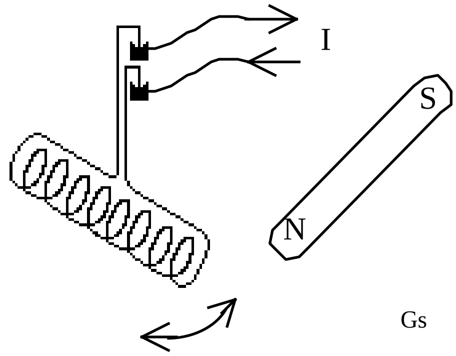


Eddy current damping on page 20.
Also, do RLC parallel circuits.

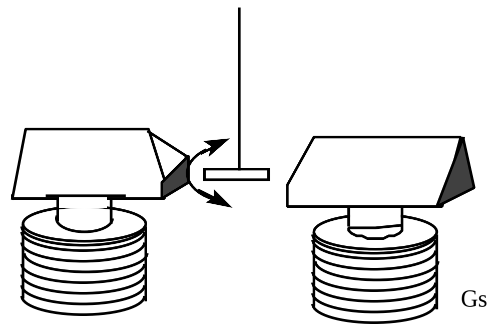
(**NOTE**: Use the video camera and large TV monitor to display the scope trace to the class.)

MAGNETIC MATERIALS

1. The equivalence of a bar magnet and a current-carrying solenoid can be shown with the same apparatus used to show the 'Torque on a current-loop' (previous section, A.4, page 16). Suspend the solenoid coil from the mercury filled cups and pass a current through it. Show that the ends of the coil look like "magnetic poles" when a bar magnet is brought nearby.

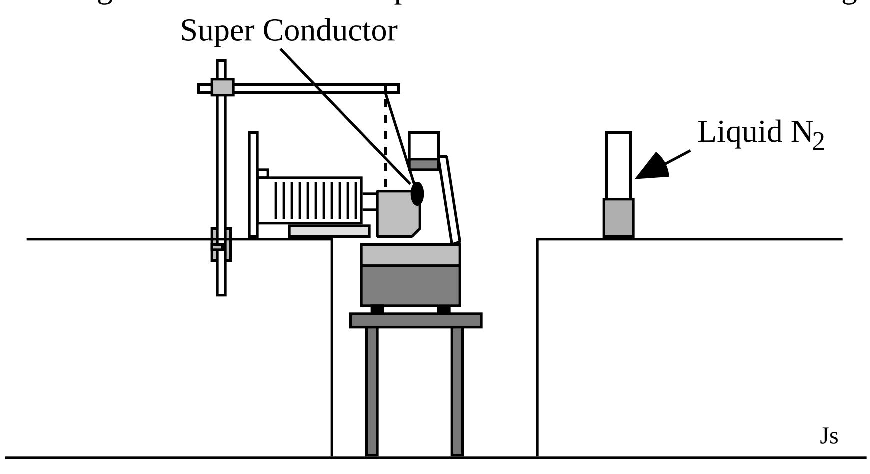


2. We have a collection of small cylinders of various materials that can be used to show dia- para- and ferromagnetism. Dia- and paramagnetism are very weak. Suspend the cylinder of interest between the poles of the large electromagnet by a fine silk thread so that it is practically torque-free. Paramagnetic cylinders will line up with axis along field, diamagnetic cylinders with axis perpendicular to field. Large effects can be obtained with Bismuth and antimony (dia-) and aluminum (para-).



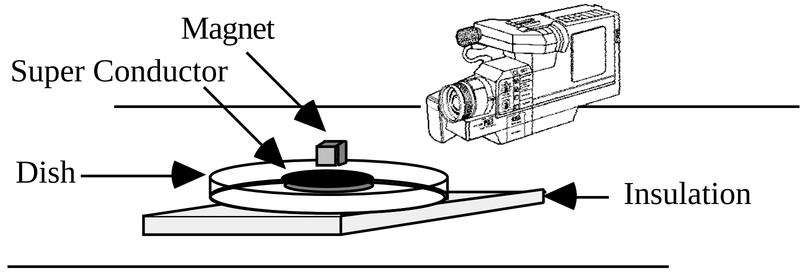
3. Superconductor:

   With approxiamately 15 amps through the electro-magnet; allow the superconductor, suspended with a string, to swing through the magnet gap. Then dip the superconductor in the liguid nitrogen and watch as the superconductor bounces off of the magnetic field.



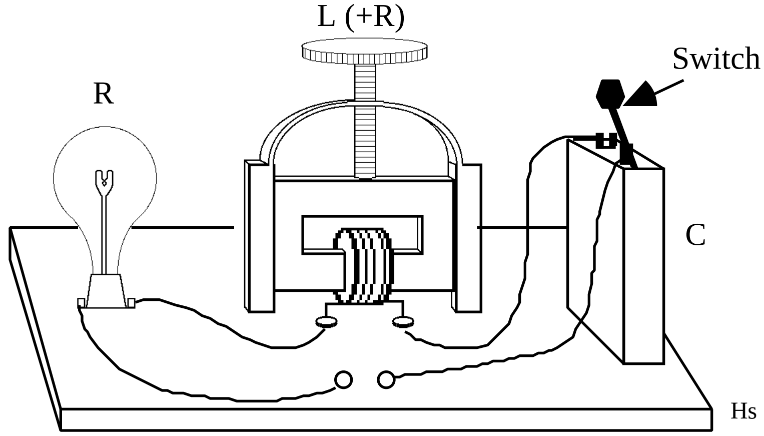
4. Floating Magnet:

   Put a superconductor in a small dish and fill with liquid nitrogen. Using non-magnetic tweezers, set the small magnet cube above the superconductor. Give a small push to start the magnet rotating.



A. C. CIRCUITS

1. Series R-L-C circuits. The vector addition of voltages can be shown with a pre-wired board that holds a light bulb, a large variable inductor and a capacitor.

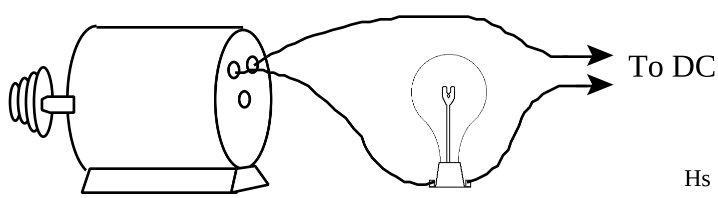


The voltage across each element can be measured with the projection voltmeter. The circuit should be adjusted near to resonance (but not on resonance) so that V_L and V_C differ appreciably. (The inductor has a resistance, so its voltage is not at right angles to V_R.
(NOTE: The resistor across the capacitor switch will bleed off any charge after the apparatus is turned off. This will prevent unexpected shocks.)

2. Series resonance. The above circuit can be used to show series resonance. Measure the voltage across the capacitor with the projection meter. Tune the inductor for V_C = maximum. (The resonance can also be observed by the brightness of the light bulb.)

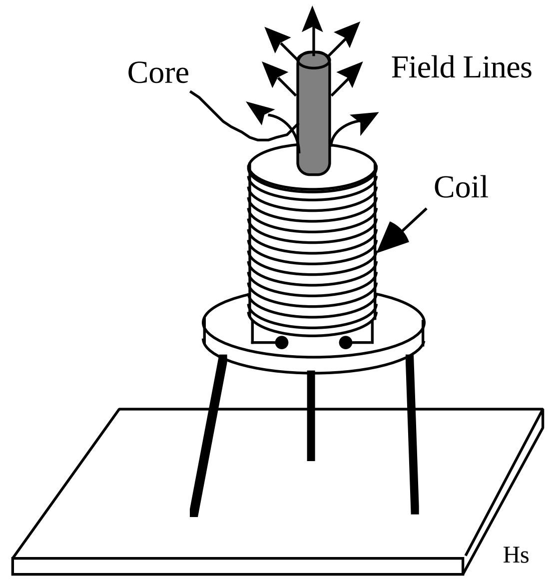
3. Applications of A. C. Circuits.

a) Back EMF's. This is not really an "A. C. " experiment, but it involves induced EMF's. Connect the 110 volt D. C. motor in series with a 100-200 watt light bulb to the 110 volt D. C. power supply:

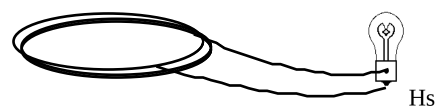


When the supply is switched on, the bulb glows brightly. As the motor speeds up, the bulb's light will decrease as the current decreases. The motor can be stalled by gripping the pulley, using a rag as a cushion. The bulb then glows brightly since the back EMF is zero.

b) There are several experiments that make use of a large iron-core coil:



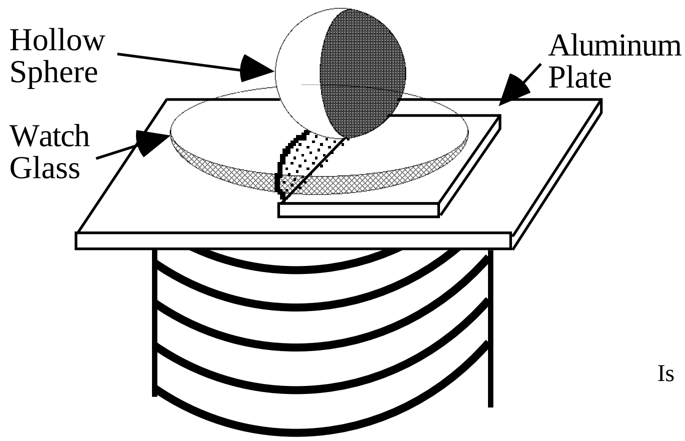
1) Transformer. The coil is supplied with 110 volt A. C. 60 cycle power. A small coil with an auto light bulb can be slipped over the core. As it is lowered, the bulb's brightness increases. (Since the flux lines "leak out" of the core, there is a larger flux linkage at lower positions.)



2) Jumping ring. If copper or aluminum ring is placed over the core, it will rest on the top of the coil. When the coil is energized, the ring will leap upward several feet. This is due to the interaction of the "leaking" flux lines with the induced current in the ring. (To get a non-zero net average force, it is necessary to take into account both the resistance and the inductance of the ring.) Ask a student to sense the force by holding the ring down on the core. The ring quickly becomes too hot to handle!

Also, the rings can be dipped in **liquid nitrogen** , it will now jump a little higher than before. The cooling lowers the resistance of the ring and allows more current to flow as well as altering the phase shift to improve the repulsive force. The results must be discussed in terms of relative inductance and the reactance of the ring.

3) "Shaded pole" motor. This is hard to explain, but fun to show. Lower the core so that its end is flush with the top of the coil. Place an aluminum plate half way over the core. Place a watch glass over the plate and put the hollow metal sphere (half copper, half nickel) on the watch glass. When the coil is energized, the sphere will start to spin. Hold the plate and watch-glass firmly and adjust for maximum effect.



Ball rotates in one direction when contact with watch glass is at x, in the other direction when contact at o.