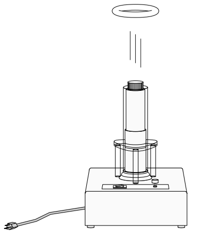
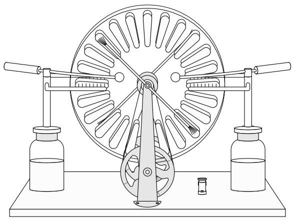
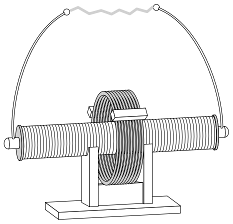
Notebook 'D':
Electricity and Magnetism
Lecture Demonstrations



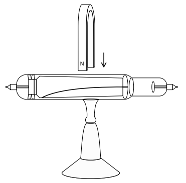
Jumping Ring



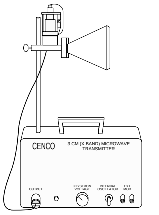
Wimshurst Machine



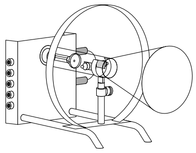
Tesla Coil



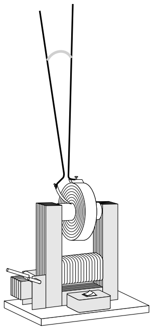
Cathode Ray Tube



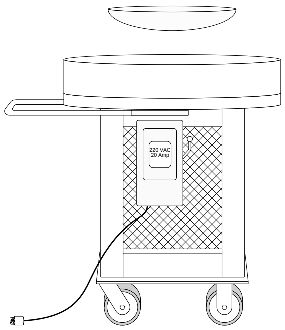
Microwaves



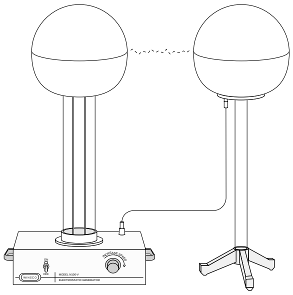
Braun Tube



Jacob's Ladder



Levitator



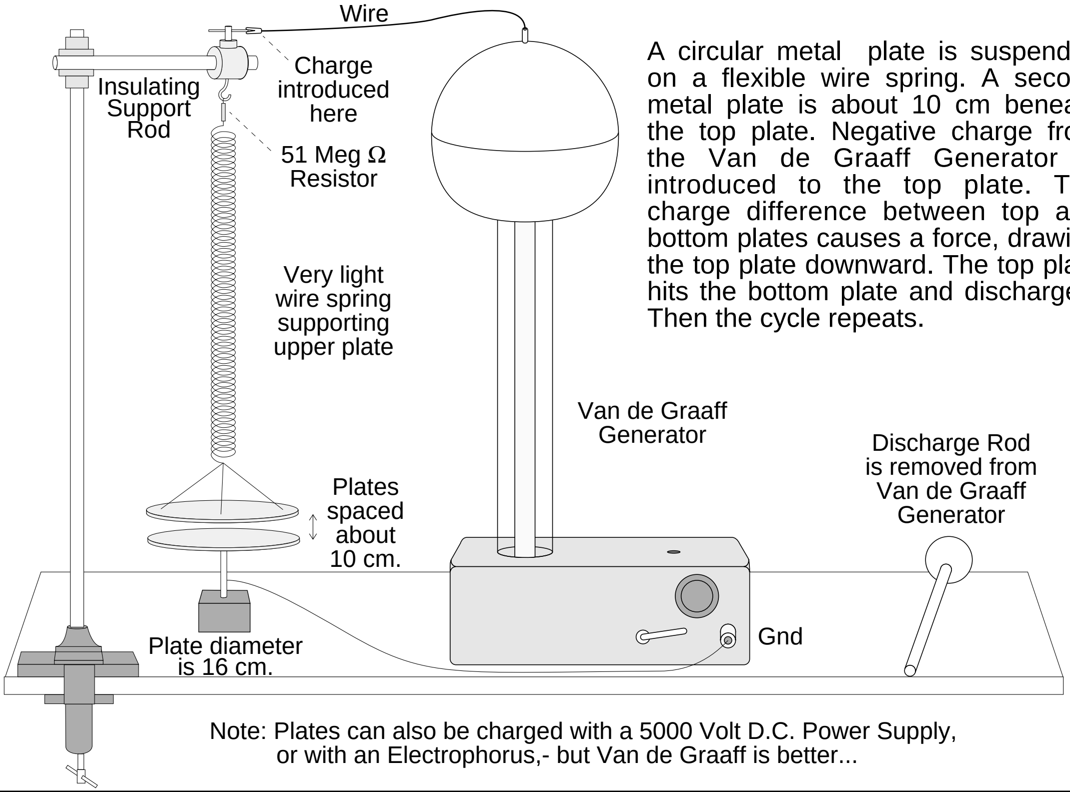
Van de Graaff

CAPACITANCE.

D+0+0

Attraction between horizontal plates of a charged capacitor.

A circular metal plate is suspended on a flexible wire spring. A second metal plate is about 10 cm beneath the top plate. Negative charge from the Van de Graaff Generator is introduced to the top plate. The charge difference between top and bottom plates causes a force, drawing the top plate downward. The top plate hits the bottom plate and discharges. Then the cycle repeats.

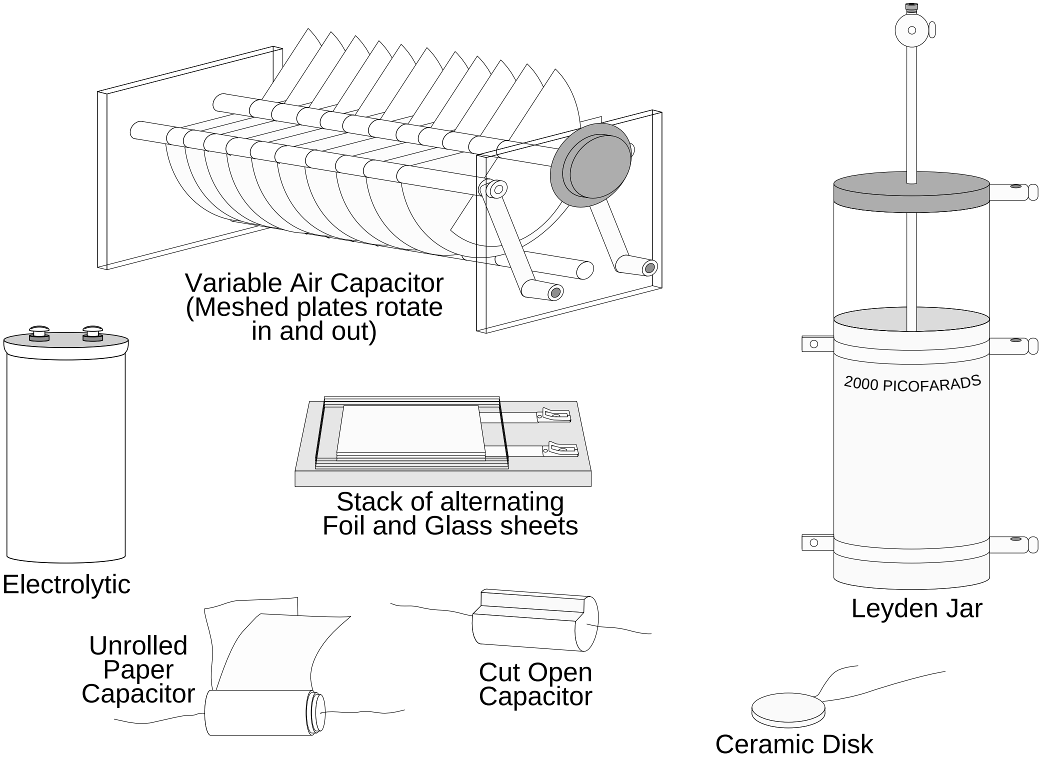


Note: Plates can also be charged with a 5000 Volt D.C. Power Supply, or with an Electrophorus,- but Van de Graaff is better...

CAPACITANCE.

D+0+2

Various Capacitors to show.



NOTE: There are many other capacitors not shown here...

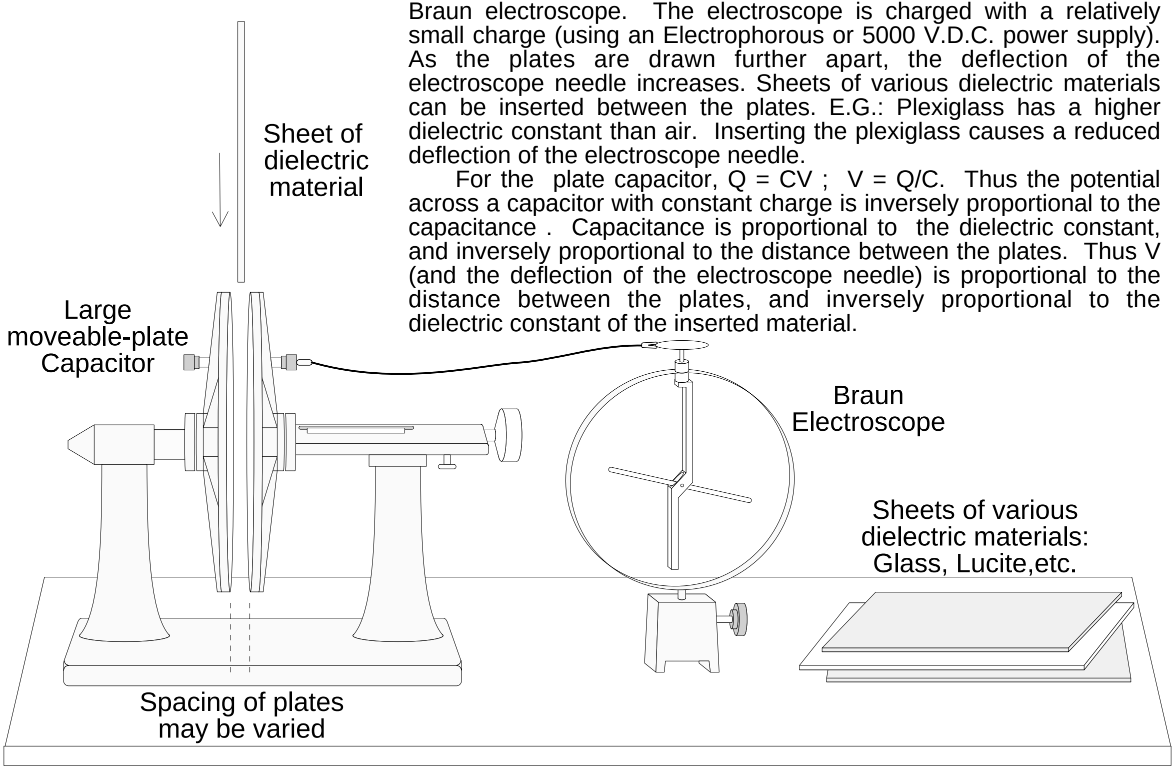
CAPACITANCE.

D+0+4

Parallel plate capacitor with dielectric materials and electroscope.

One of the plates of the parallel-plate capacitor is connected to a Braun electroscope. The electroscope is charged with a relatively small charge (using an Electrophorous or 5000 V.D.C. power supply). As the plates are drawn further apart, the deflection of the electroscope needle increases. Sheets of various dielectric materials can be inserted between the plates. E.G.: Plexiglass has a higher dielectric constant than air. Inserting the plexiglass causes a reduced deflection of the electroscope needle.

For the plate capacitor, Q = CV ; V = Q/C. Thus the potential across a capacitor with constant charge is inversely proportional to the capacitance . Capacitance is proportional to the dielectric constant, and inversely proportional to the distance between the plates. Thus V (and the deflection of the electroscope needle) is proportional to the distance between the plates, and inversely proportional to the dielectric constant of the inserted material.

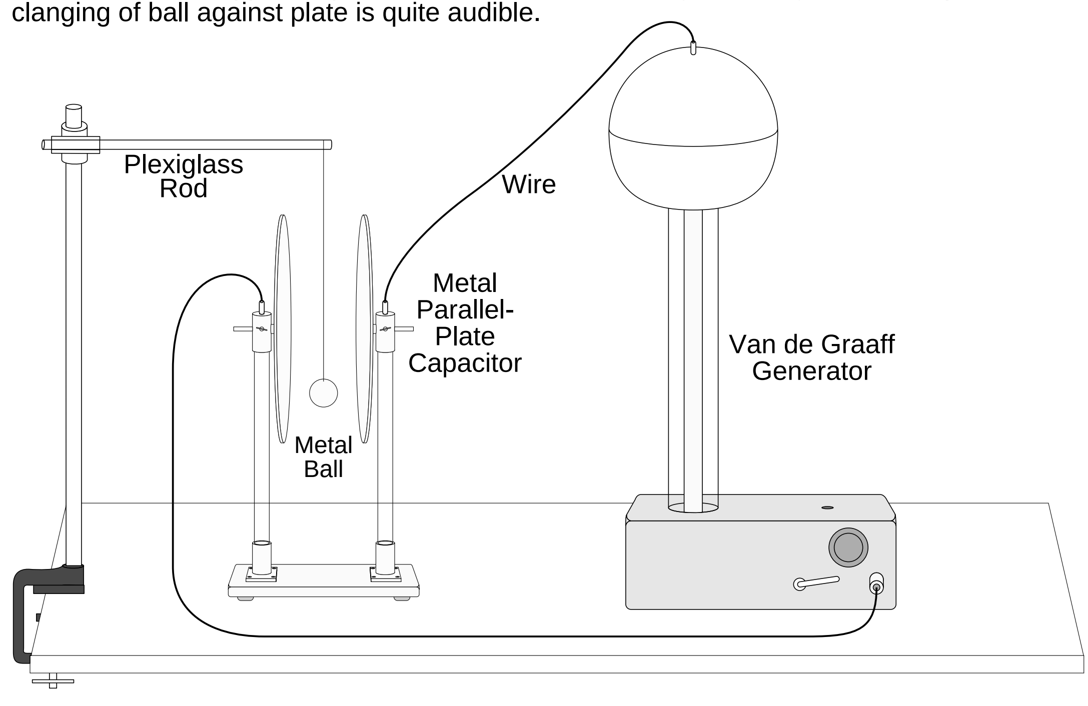


CAPACITANCE.

D+0+6

Capacitor doorbell driven by Van de Graaff generator.

Negative charge from the Van de Graaf generator builds up on one plate. The metal ball, initially uncharged, is attracted to the negative plate and hits it, becoming negative also. It rebounds to the opposite plate where it loses its charge. The cycle then repeats. The clanging of ball against plate is quite audible.



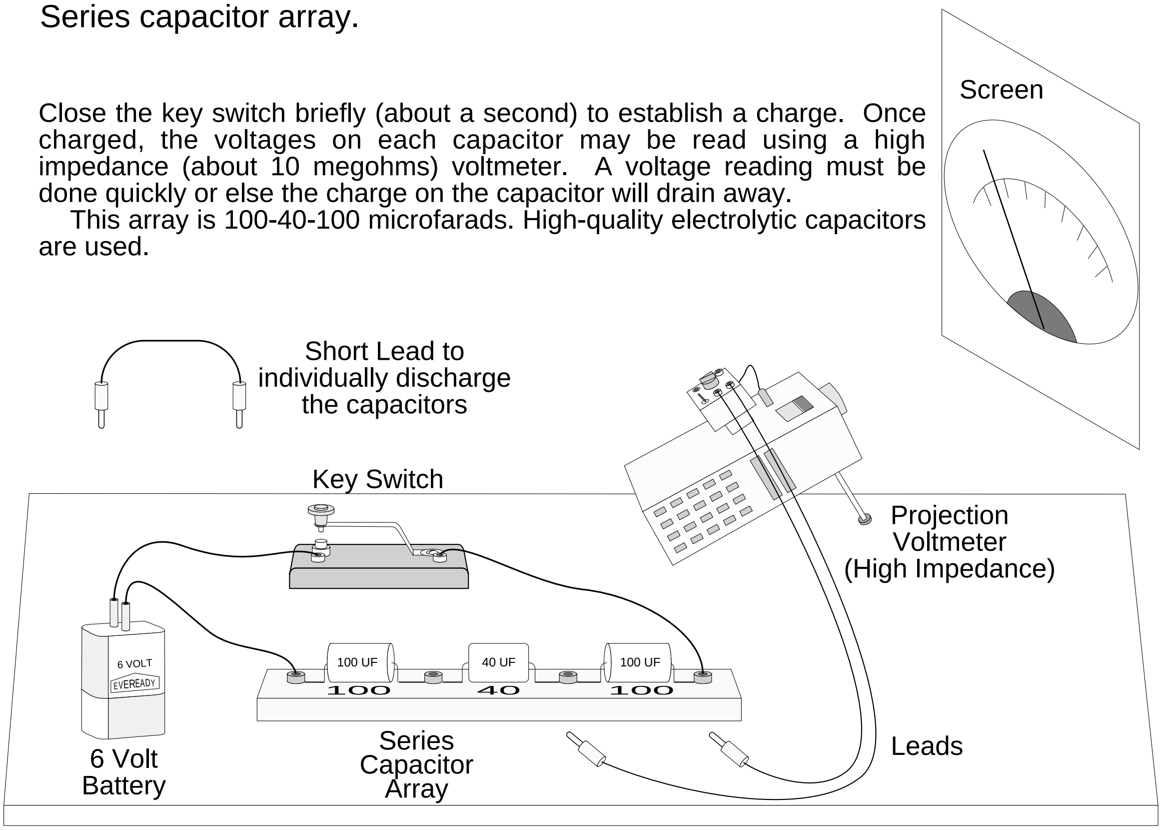
CAPACITANCE.

D+0+8

Series capacitor array.

Close the key switch briefly (about a second) to establish a charge. Once charged, the voltages on each capacitor may be read using a high impedance (about 10 megohms) voltmeter. A voltage reading must be done quickly or else the charge on the capacitor will drain away.

This array is 100-40-100 microfarads. High-quality electrolytic capacitors are used.

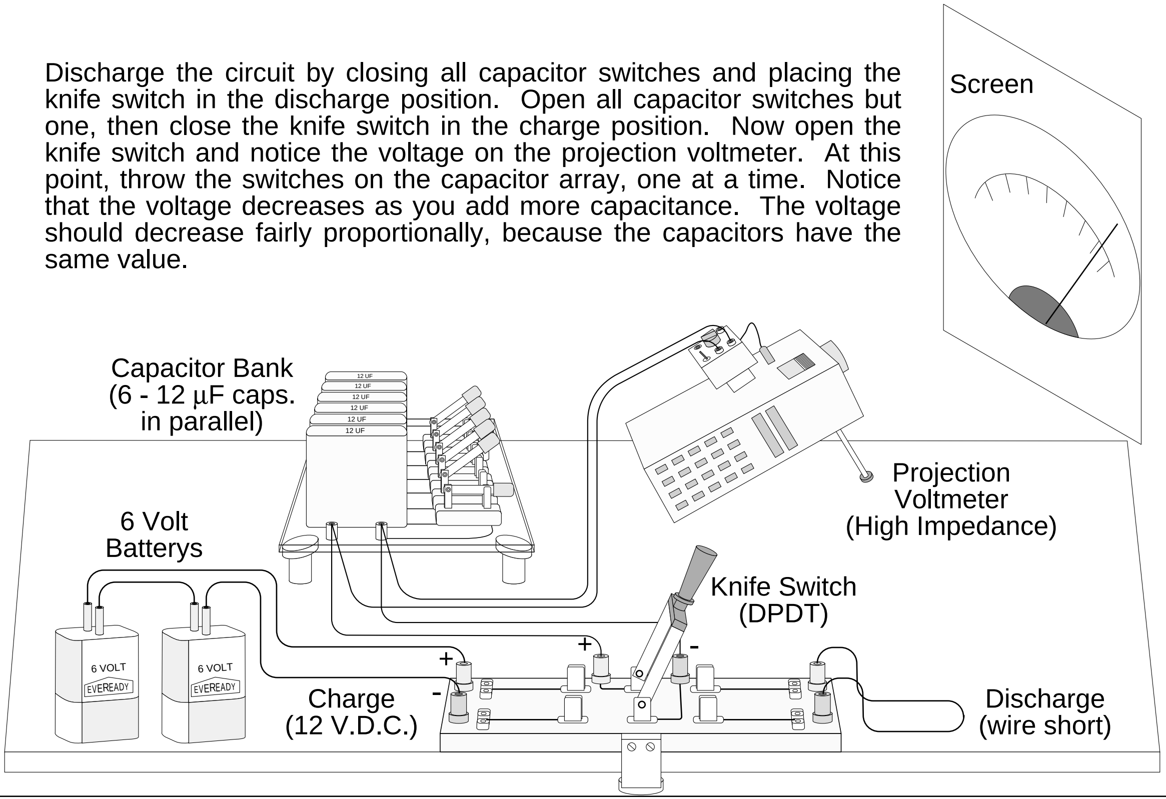


CAPACITANCE.

D+0+10

Parallel capacitor array: A charged capacitor charges the others.

Discharge the circuit by closing all capacitor switches and placing the knife switch in the discharge position. Open all capacitor switches but one, then close the knife switch in the charge position. Now open the knife switch and notice the voltage on the projection voltmeter. At this point, throw the switches on the capacitor array, one at a time. Notice that the voltage decreases as you add more capacitance. The voltage should decrease fairly proportionally, because the capacitors have the same value.

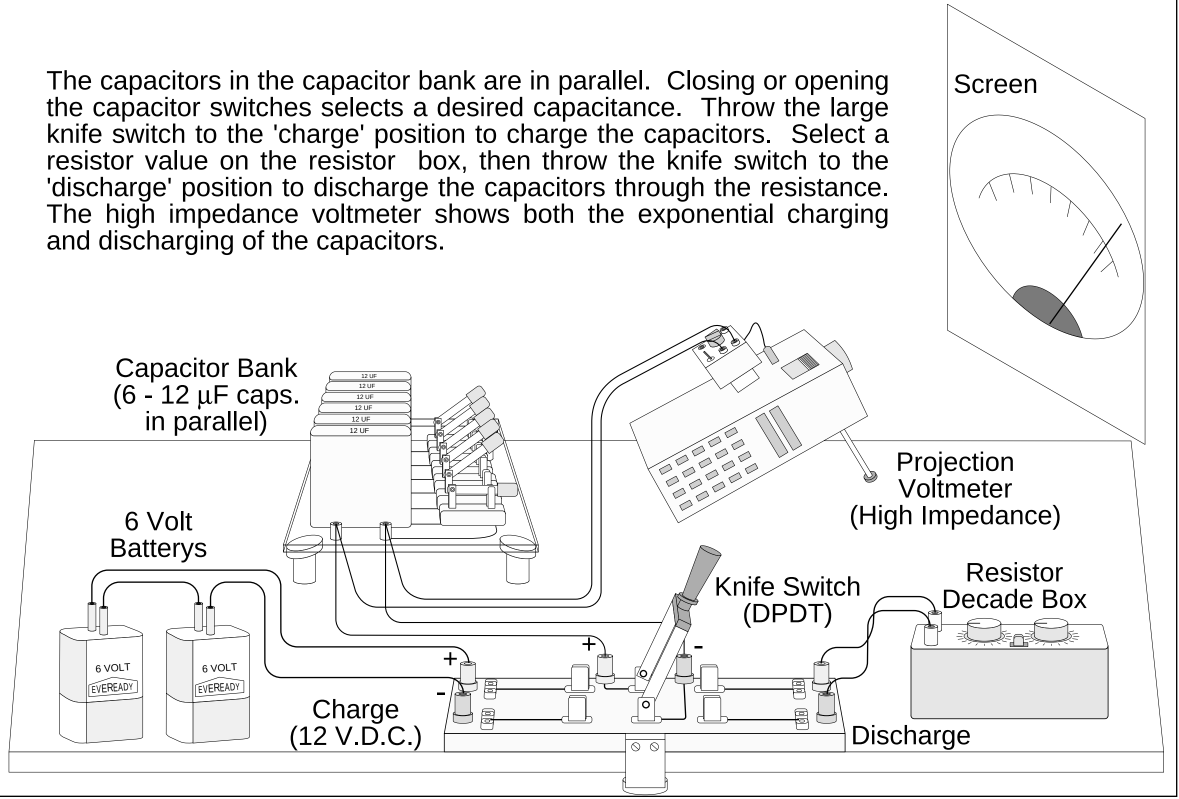


CAPACITANCE.

D+0+12

Visual charge/discharge of a capacitor through a load.

The capacitors in the capacitor bank are in parallel. Closing or opening the capacitor switches selects a desired capacitance. Throw the large knife switch to the 'charge' position to charge the capacitors. Select a resistor value on the resistor box, then throw the knife switch to the 'discharge' position to discharge the capacitors through the resistance. The high impedance voltmeter shows both the exponential charging and discharging of the capacitors.

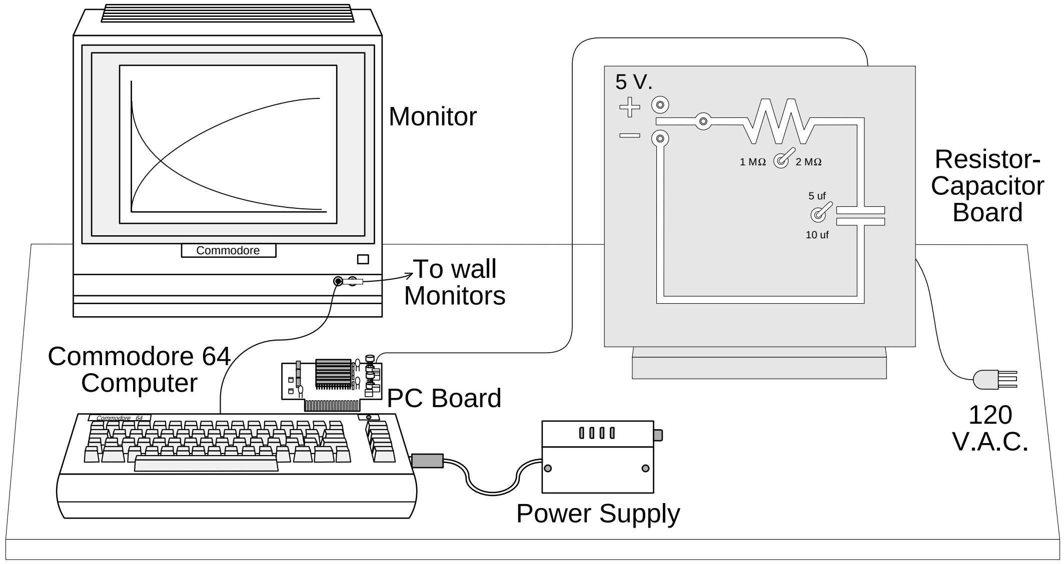


CAPACITANCE.

D+0+14

Computer Demo: Charge/discharge of a capacitor, runs 3 minutes.

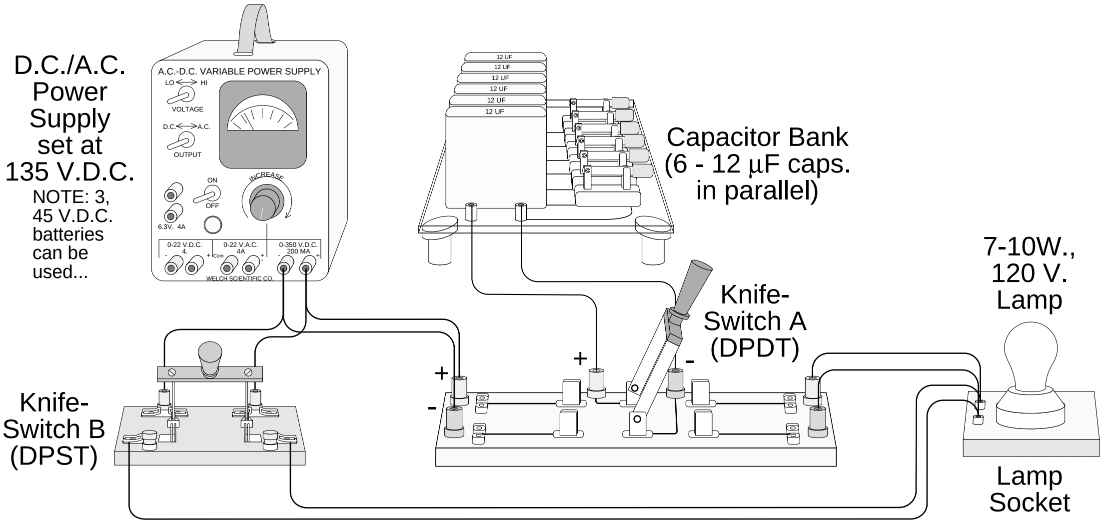
This program plots voltage versus time for the charging and discharging of a capacitor through a series resistor. Two values of resistor (1 Meg Ω or 2 Meg Ω) and 2 values of capacitor (5 μf or 10 μf) can be chosen. After the plot is finished (3 min.) , you can input the values of the resistor and capacitor used, and the computer will calculate the value of the time constant and compare it with the measured value.
NOTE: Switches on the back of the resistor-capacitor board allow one to manually charge and discharge the capacitor. Output can be sent to an oscilloscope.



CAPACITANCE. D+0+16

Discharging a capacitor through a lamp.

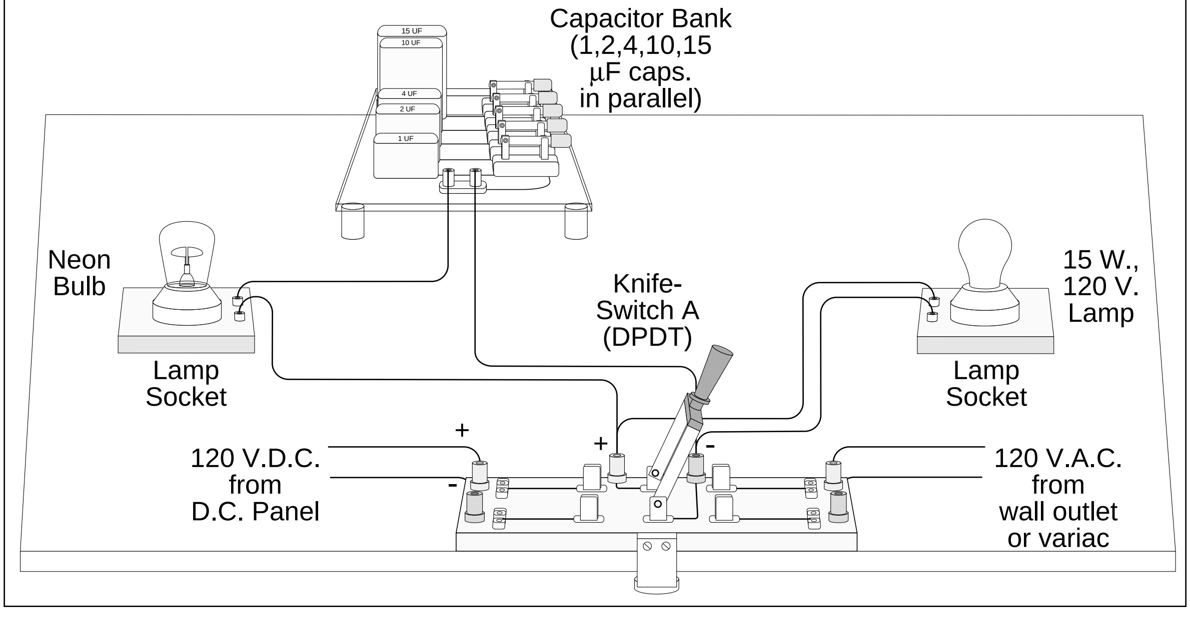
Throw knife-switch A to the left to charge the capacitor bank with 135 V.D.C. Throw Switch A to the right to discharge the capacitor bank through the lamp, causing a flash. Close knife-switch B to put 135 V.D.C. across the lamp, causing it to glow continuously.



CAPACITANCE. D+0+18

Capacitors with a series neon bulb on A.C. and D.C..

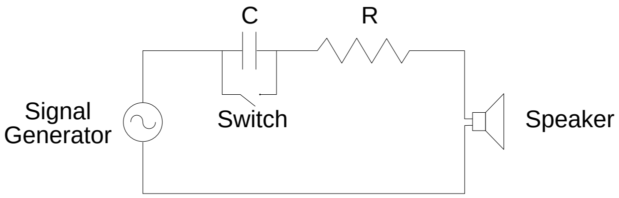
Throw knife-switch A to the left to put 120 V.D.C. across the series capacitor and neon bulb circuit. The breakdown voltage of the neon in the neon bulb is about 70 volts, but only one of the two semi-circular electrodes in the bulb glows briefly. Throw Switch A to the right to put 120 V.A.C. across the capacitor and neon bulb circuit. Now both electrodes of the neon bulb glow. In both the D.C. and A.C. cases, the regular 15 watt tungsten filament lamp glows continuously.

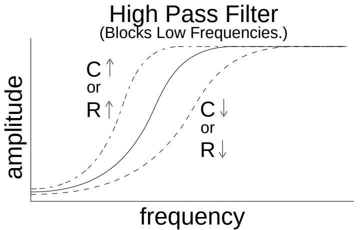


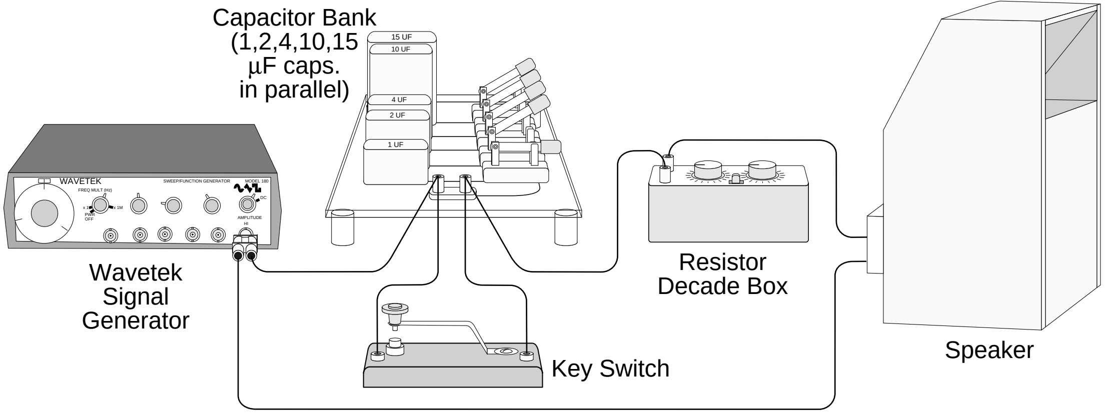
CAPACITANCE. D+0+20

Capacitor in series in an audio circuit: High pass filter.

A variable audio oscillator is hooked to a capacitor and resistor in series. The circuit passes high frequencies and blocks low frequencies, as can be heard with the speaker. Capacitance and resistance can be varied. A good set of starting values is 1 μf capacitance, and 15 Ω resistance. Maximum signal is at 20 KHz; signal is attenuated by 50% at 760 Hz (6 db down); and by 90% at 260 Hz (20 db down). Closing or opening the key-switch allows one to check the frequency attenuation.







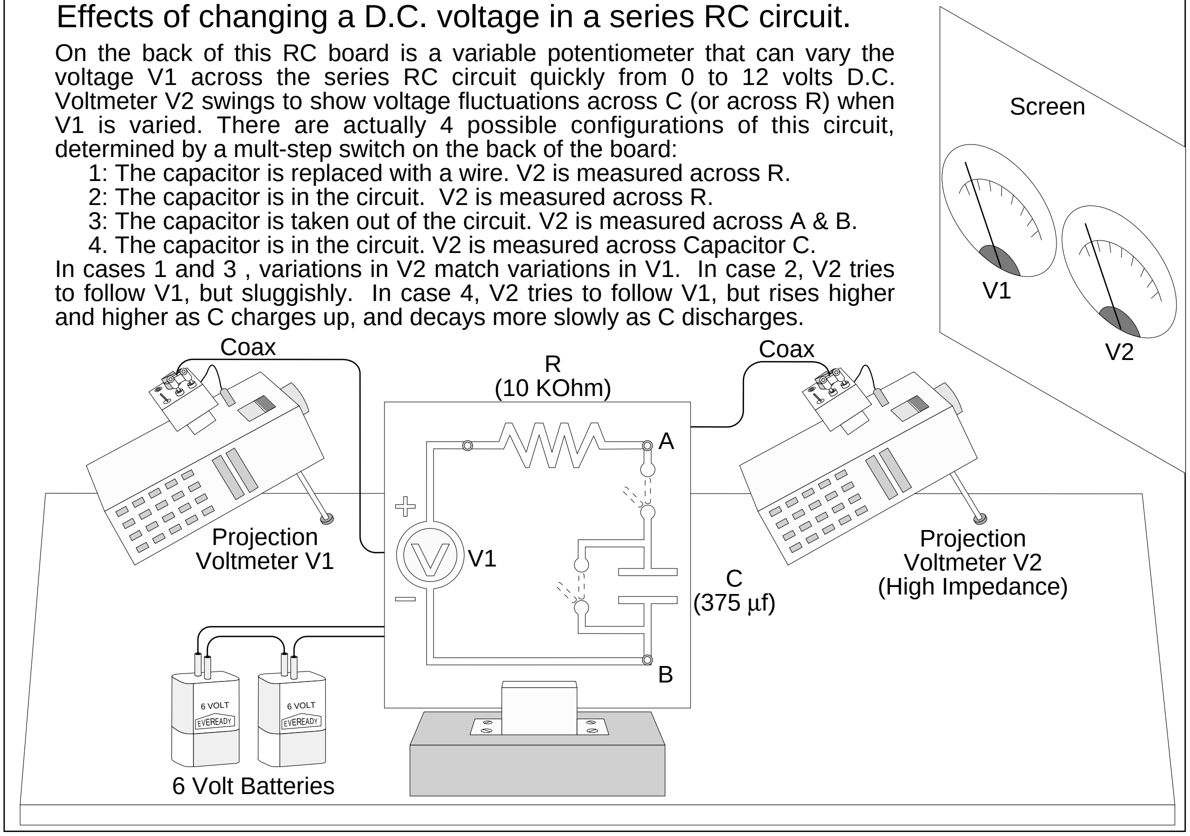
CAPACITANCE. D+0+22

Effects of changing a D.C. voltage in a series RC circuit.

On the back of this RC board is a variable potentiometer that can vary the voltage V1 across the series RC circuit quickly from 0 to 12 volts D.C. Voltmeter V2 swings to show voltage fluctuations across C (or across R) when V1 is varied. There are actually 4 possible configurations of this circuit, determined by a mult-step switch on the back of the board:

1: The capacitor is replaced with a wire. V2 is measured across R.
2: The capacitor is in the circuit. V2 is measured across R.
3: The capacitor is taken out of the circuit. V2 is measured across A & B.
4. The capacitor is in the circuit. V2 is measured across Capacitor C.

In cases 1 and 3 , variations in V2 match variations in V1. In case 2, V2 tries to follow V1, but sluggishly. In case 4, V2 tries to follow V1, but rises higher and higher as C charges up, and decays more slowly as C discharges.

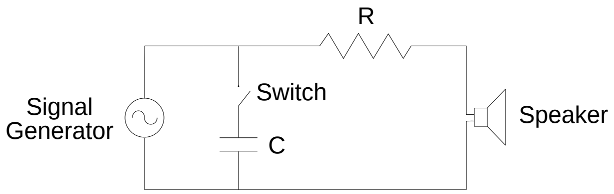


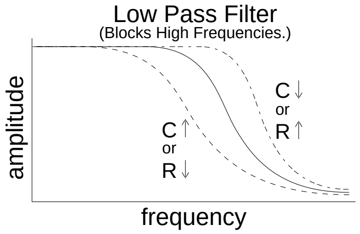
CAPACITANCE.

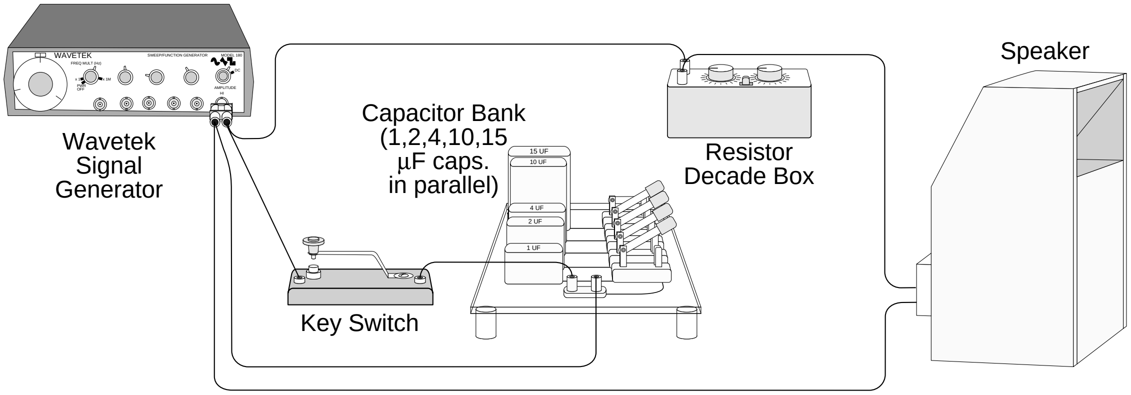
D+0+24

Capacitor in parallel in an audio circuit: Low pass filter.

A variable audio oscillator is hooked to a capacitor and resistor in parallel. The circuit passes low frequencies and blocks high frequencies, as can be heard with the speaker. Capacitance and resistance can be varied. A good set of starting values is 15 µf capacitance, and 100 Ω resistance. Maximum signal is at 20 Hz; signal is attenuated by 50% at 1800 Hz (6 db down); and by 90% at 5400 Hz (20 db down). Closing or opening the key-switch allows one to check the frequency attenuation.



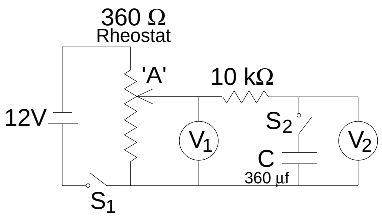




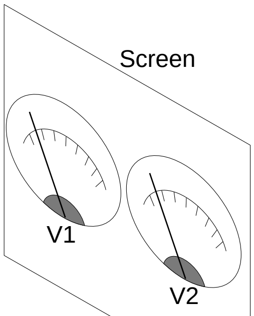
CAPACITANCE.

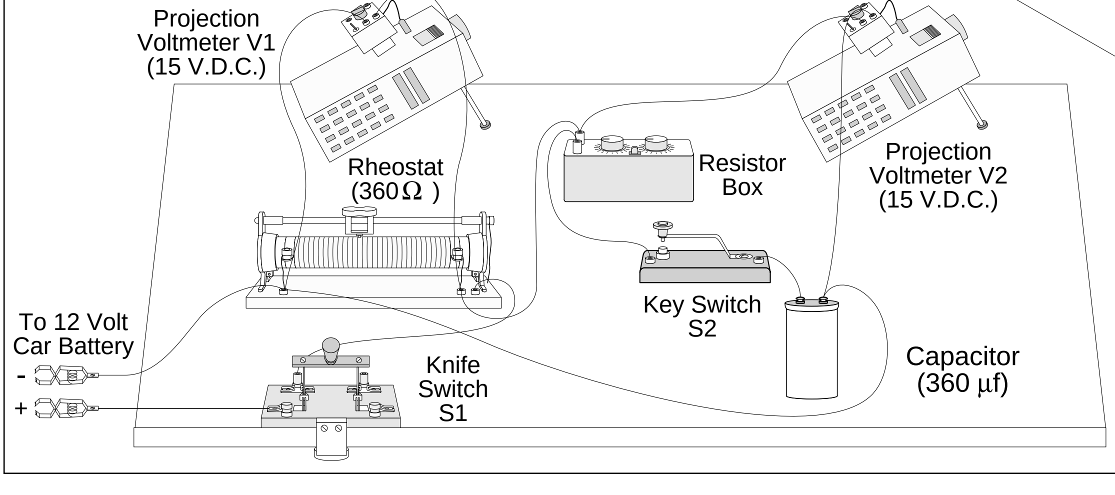
D+0+26

Capacitor in parallel in a D.C. circuit.



When switch S1 is closed, 12 V.D.C. is put across a 360 ohm slidewire rheostat. Moving the slider on the rheostat varies the voltage at 'A' from 0 to 12 V. When capacitor C (360 µf) is not in the circuit (switch S2 open), rapidly moving the rheostat slider causes voltmeters 1 and 2 to swing quickly and equally to read voltage changes. When C is in the circuit (S2 closed), voltmeter 1 swings quickly to read voltage changes, but voltmeter 2 responds slowly. Thus, when C is in the circuit, time variations are smoothed out.



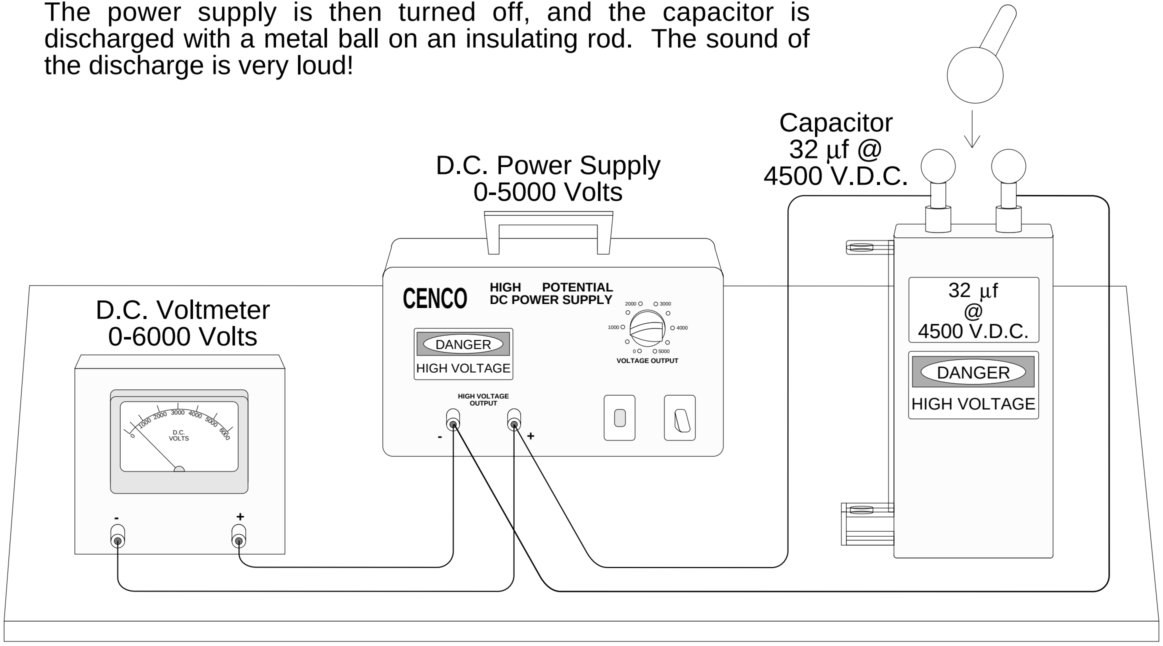


CAPACITANCE. D+0+28

Energy storage in a commercial capacitor. Loud bang!

A high voltage D.C. power supply is used to charge a large commercial capacitor. The power supply is set at about 2500 volts, and the capacitor is allowed to charge for a minute or so. The power supply is then turned off, and the capacitor is discharged with a metal ball on an insulating rod. The sound of the discharge is very loud!

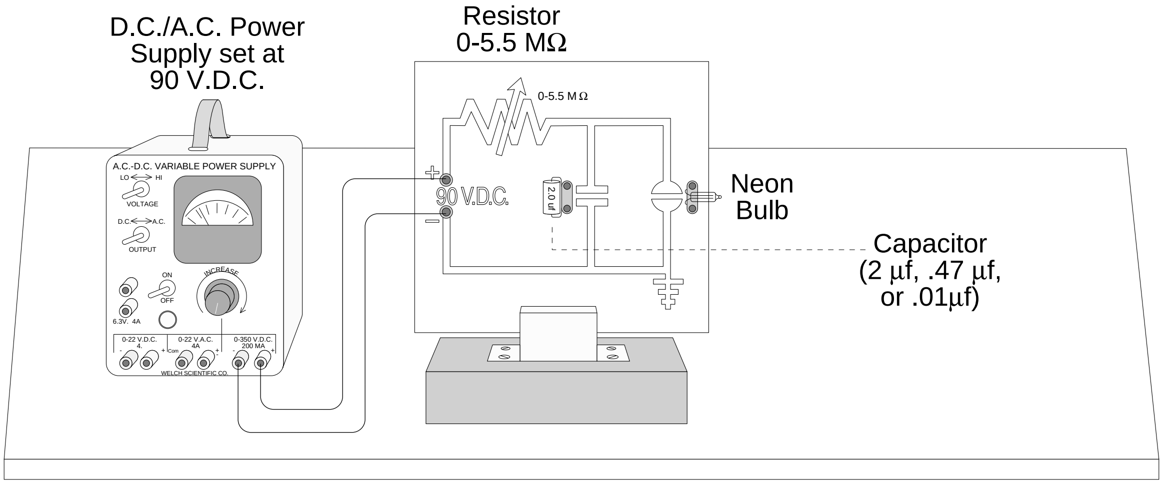
Brass Ball with insulated handle to discharge capacitor.



CAPACITANCE. D+0+30

Oscillator made with resistor, capacitor and neon lamp.

90 Volts D.C. is put across a series RC circuit. A neon bulb is in parallel with the capacitor. When the capacitor charges up to 80 volts, the neon bulb flashes (breakdown voltage for this neon bulb is about 80 volts), draining the capacitor charge. The capacitor then begins to charge again, and the cycle repeats. The period T of the flashes of the bulb is the product of the Resistance and Capacitance (RxC). The resistance can be varied from 0 to 5.5 M Ω, and three different capacitors can be plugged in: 2 µf, .47 µf, and .01 µf.

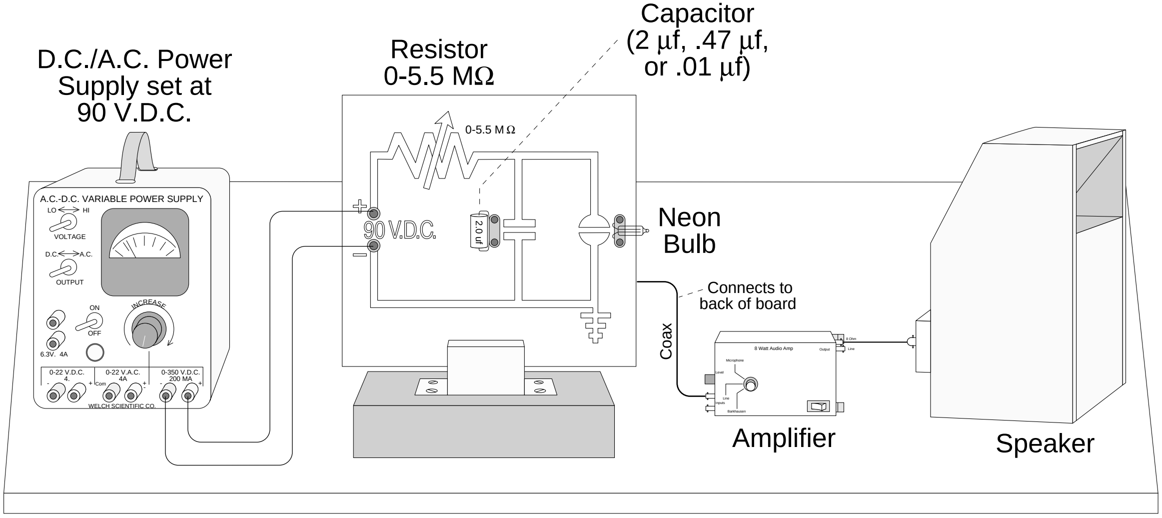


CAPACITANCE. D+0+32

Same as D+0+30 using speaker for audio tone generation.

90 Volts D.C. is put across a series RC circuit. A neon bulb is in parallel with the capacitor. When the capacitor charges up to 80 volts, the neon bulb flashes (breakdown voltage for this neon bulb is about 80 volts), draining the capacitor charge. The capacitor then begins to charge again, and the cycle repeats. The period T of the flashes of the bulb is the product of the Resistance and Capacitance (RxC). The resistance can be varied from 0 to 5.5 M Ω, and three different capacitors can be plugged in: 2 µf, .47 µf, and .01 µf.

The oscillating signal produced in this demo is amplified and made audible with a speaker.The signal frequency f = 1/T.

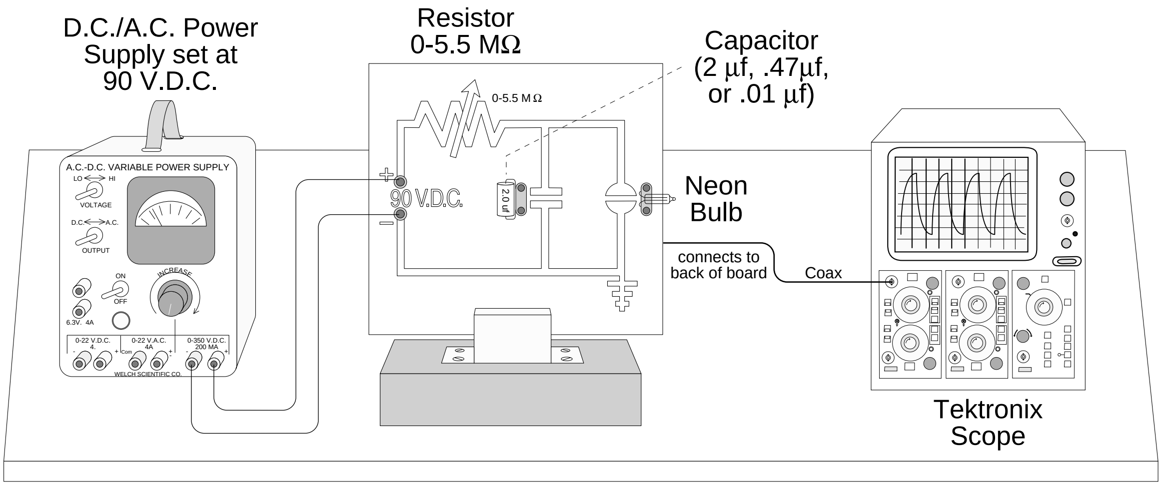


CAPACITANCE. D+0+34

Same as D+0+30 using oscilloscope to display waveform.

90 Volts D.C. is put across a series RC circuit. A neon bulb is in parallel with the capacitor. When the capacitor charges up to 80 volts, the neon bulb flashes (breakdown voltage for this neon bulb is about 80 volts), draining the capacitor charge. The capacitor then begins to charge again, and the cycle repeats. The period T of the flashes of the bulb is the product of the Resistance and Capacitance (RxC). The resistance can be varied from 0 to 5.5 M Ω, and three different capacitors can be plugged in: 2 µf, .47 µf, and .01 µf.

The oscillating signal produced in this demo is displayed on an oscilloscope. The signal frequency f = 1/T. (A speaker can also be attached to make the signal audible, as in D+0+32.)



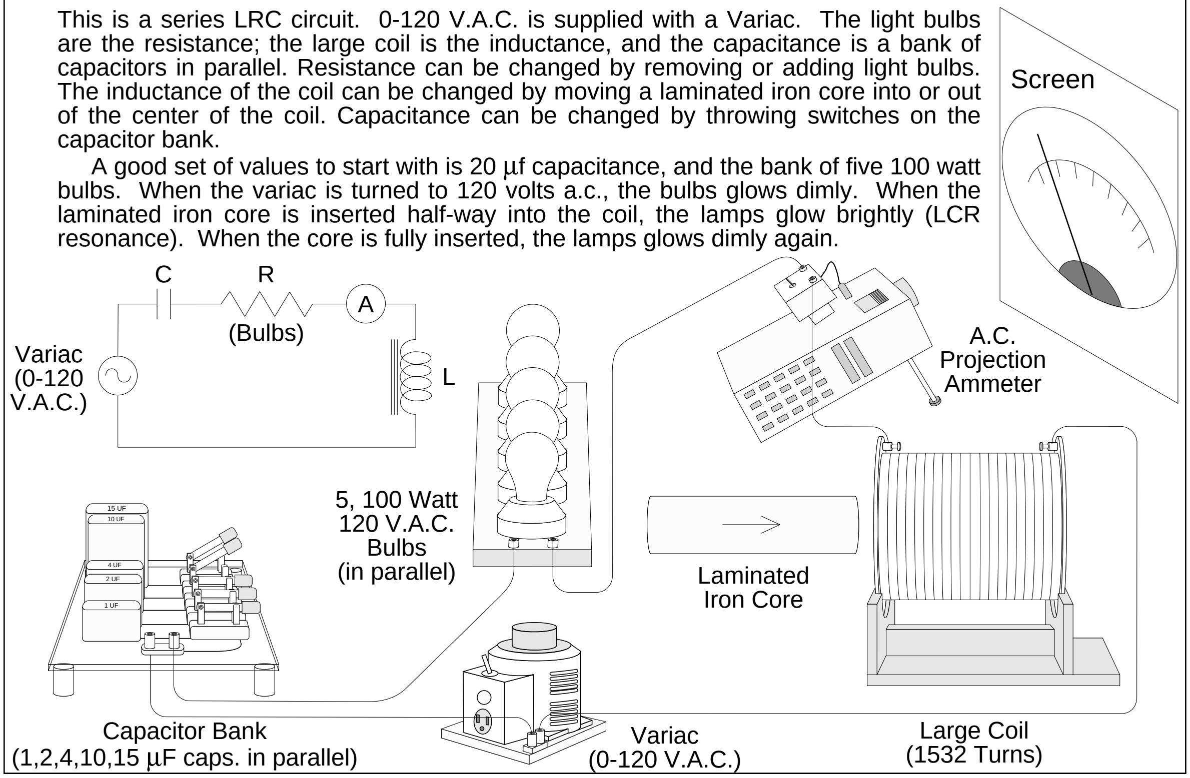
ELECTROMAGNETIC OSCILLATIONS.

D+5+0

Resonance in a series LCR circuit using 120 v.a.c.

This is a series LRC circuit. 0-120 V.A.C. is supplied with a Variac. The light bulbs are the resistance; the large coil is the inductance, and the capacitance is a bank of capacitors in parallel. Resistance can be changed by removing or adding light bulbs. The inductance of the coil can be changed by moving a laminated iron core into or out of the center of the coil. Capacitance can be changed by throwing switches on the capacitor bank.

A good set of values to start with is 20 µf capacitance, and the bank of five 100 watt bulbs. When the variac is turned to 120 volts a.c., the bulbs glows dimly. When the laminated iron core is inserted half-way into the coil, the lamps glow brightly (LCR resonance). When the core is fully inserted, the lamps glows dimly again.



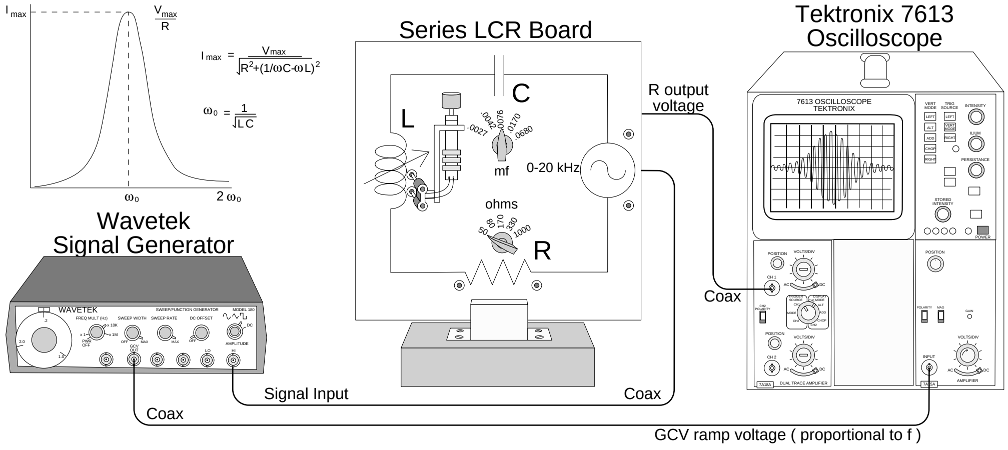
ELECTROMAGNETIC OSCILLATIONS.

D+5+2

LCR series resonance curve of V vs. F (2-20 kHz) on an oscilloscope.

In this series LCR circuit, a signal generator sweeps from 2 kHz to 20 kHz, and the amplitude of the circuit current (measured as voltage across the resistor) is displayed versus frequency on the oscilloscope screen. Using the variable inductor (16-36 mh) and the .0076 µf capacitor, peak resonance is from 8-13 kHz, approximately in the center of the screen. Inductance, resistance and capacitance can all be varied. To move the resonance peak left or right on the screen, vary either the inductance or capacitance. To change the 'Q' (or sharpness) of the resonance peak, change the resistance.

Set-up Notes: The time base of the scope is replaced with a plug-in amp, controlling the horizontal motion of the beam. This amp is driven by the GCV output of the signal generator (a ramp proportional to the frequency). The signal generator drives the LCR circuit (co-ax connection on back of board). The voltage across the resistor (coax-connector, back of board) is the input to the vertical amp on the scope. Use .1 V/Div for both the vertical and horizontal amp plug-ins. Use the 10 KHz scale for the signal generator. To adjust the screen display: place horizontal and vertical amps on 'DC' setting. Zero the DC Offset knob, and the Sweep Width and the Sweep Rate knobs of the signal generator. First, set the frequency to 2 KHz and use the position knob on the right plug-in (horizontal sweep) to locate the vertical line at screen left. Then, set the frequency to 20 KHz, and use the 'cal' volts/div knob on the right plug-in to locate the vertical line at screen right. Then, turn the Sweep Width and the Sweep Rate knobs to full scale, with the signal generator set to 2 KHz. The signal generator should now be sweeping the LCR circuit from 2-20 KHz, and the frequency-response plot should be displayed on the scope.



$$I_{max} = \frac{V_{max}}{\sqrt{R^2+(1/\omega C\text{-}\omega L)^2}}$$

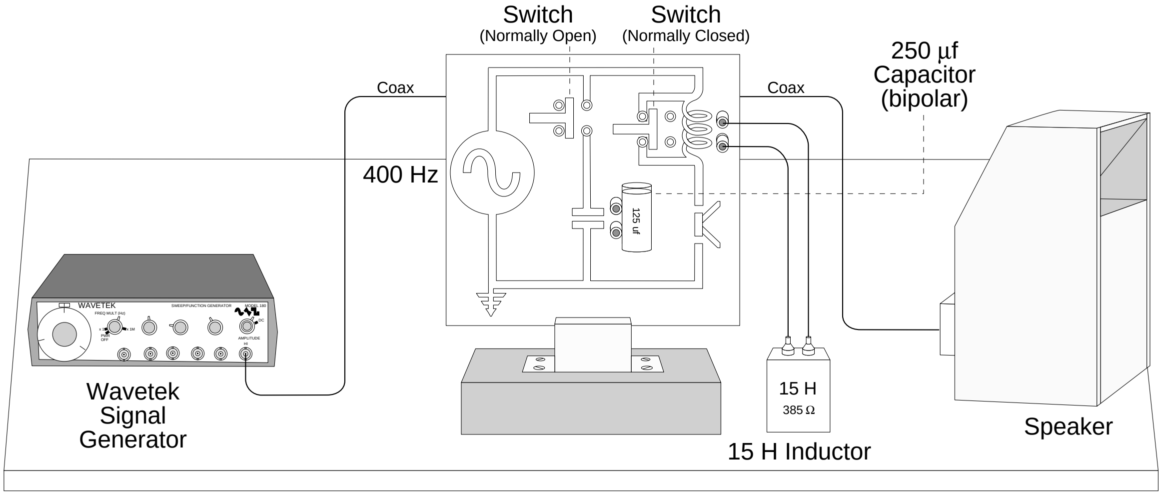
$$\omega_0 = \frac{1}{\sqrt{LC}}$$

ELECTROMAGNETIC OSCILLATIONS.

D+5+4

Low frequency filtering using a capacitor and inductor.

This demonstration shows how low frequency A.C. signals (400 Hz) are affected by a series inductor or a capacitor in parallel. A variable audio oscillator is connected via coax cable to the back of the demo board. The board is set up with switches on back so that an inductor can be placed in series with the speaker, or a capacitor can be placed in parallel with the speaker. When no switch is pressed, neither the capacitor nor inductor is in the circuit. When either the 250 µf capacitor or 15H inductor is in the circuit, the audio signal to the speaker is drastically reduced.



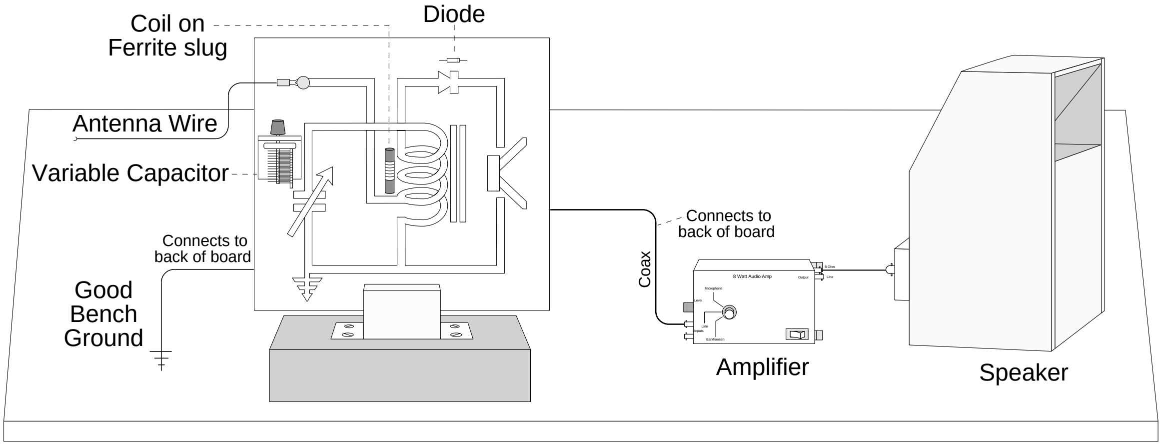
ELECTROMAGNETIC OSCILLATIONS.

D+5+6

Crystal radio circuit for AM reception.

This is a simple crystal-radio receiver circuit. An antenna wire from the roof of LeConte Hall connects to a coil wrapped on a ferrite slug which is in parallel with a variable capacitor (a 'tank' circuit). The antenna receives e-m radiation of all frequencies, giving rise to currents in the coil. The variable capacitor 'tunes' the tank circuit to resonate with the carrier frequency of any AM radio station (45-160 KHz). The signal is picked off the coil, rectified by the diode (made into an D.C. audio signal), amplified, then made audible with the speaker. To change the channel, just turn the tuning capacitor.

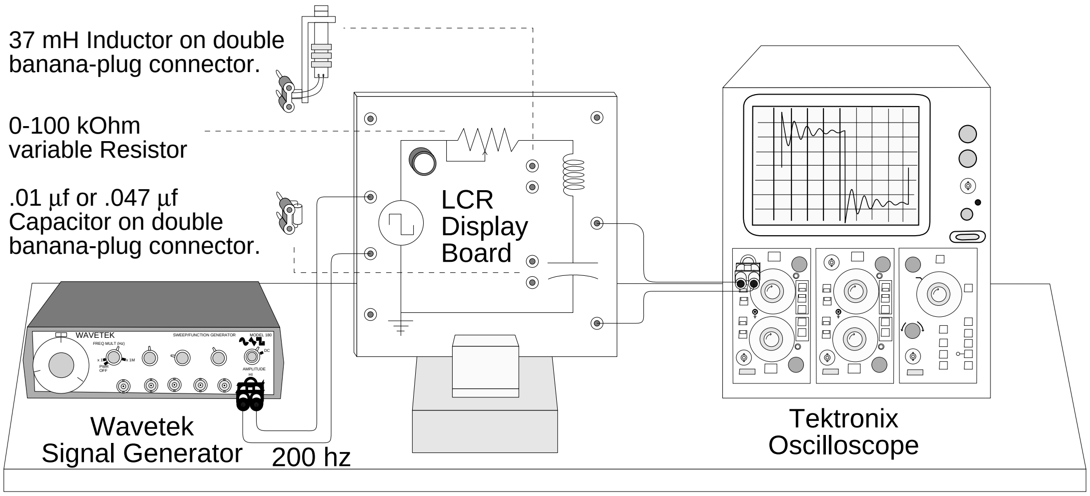
The capacitor is in the 45 -157 pf range. The inductor should be in the low milli-henry range (.05 to 1.3 mH). The high-frequency part of the detected audio signal (45-160 KHz = the carrier wave) is bled off by the capacitance of the coax cable before reaching the amp. Thus, the 20-20,000 Hz audio signal is all that is amplified.



ELECTROMAGNETIC OSCILLATIONS. D+5+8

Damped Oscillations in a resonant LCR circuit on an oscilloscope.

The various different waveforms are created by adjusting the 100k potentiometer on the LCR display board.

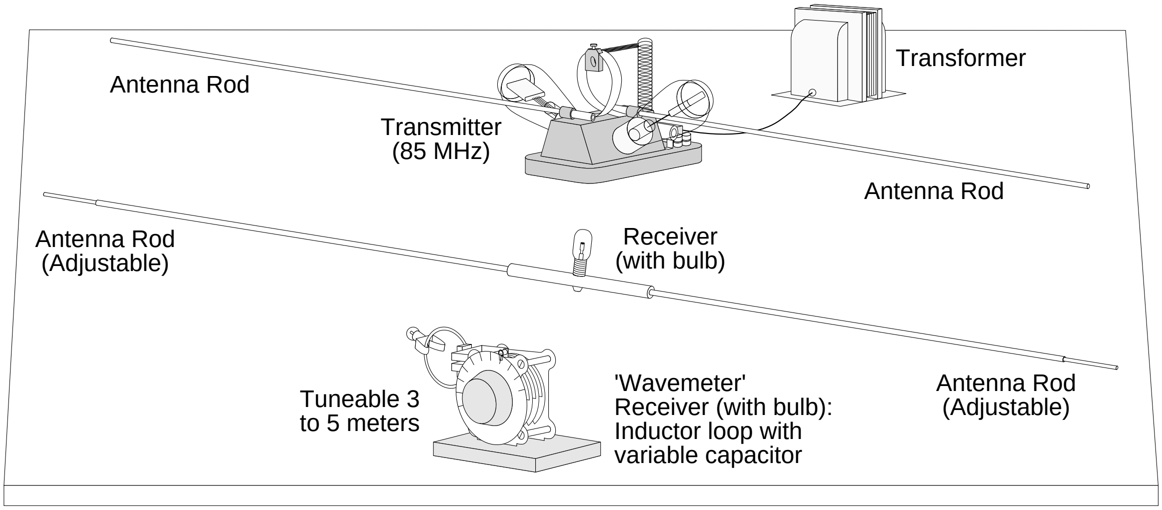


ELECTROMAGNETIC OSCILLATIONS. D+5+10

85 MHz radio transmitter, with indicating lamp on dipole antenna.

This is a simple radio transmitter and receiver demonstration apparatus. The transmitter is a high frequency vacuum tube oscillator with a fixed frequency of 85 MHz (3.5 M wavelength), powered by a transformer. Mica capacitors are mounted within the bakelite case, and the simple loop (7 cm. diameter) on top is the inductance. Horizontal copper 'sending' antennas are plugged into the ends of the inductance loop.

The first receiver is a simple linear oscillator which is a straight copper conductor connected at its middle through a small incandescent (or neon) lamp. Its length can be adjusted by means of copper rods telescoping into its ends. When the length is properly adjusted so that it oscillates at the frequency of the transmitter, the lamp glows brilliantly within a meter of the transmitter, and continues to glow at several meters. The second type of receiver ('wavemeter')consists of an inductance loop, and a variable capacitor. The receiver can be tuned from 3 to 5 meters wavelength, lighting the pilot lamp.

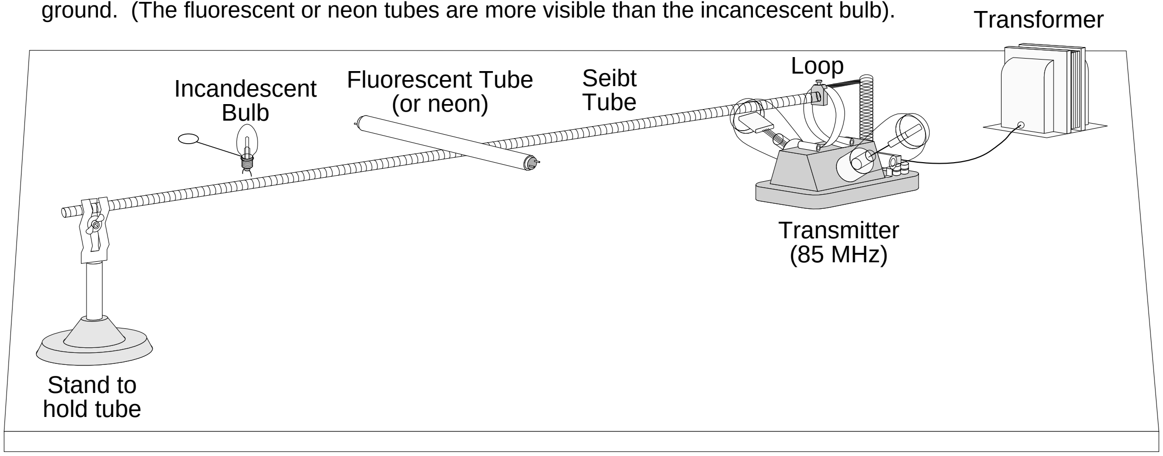


ELECTROMAGNETIC OSCILLATIONS.

D+5+12

Seibt effect: Wire wound glass tube with D+5+10 transmitter. Standing waves.

The radio transmitter is a high frequency vacuum tube oscillator with a fixed frequency of 85 MHz (3.5 meter wavelength), powered by a transformer. (See D+5+10). The 'Seibt Tube' demonstrates standing radio waves, on what is effectively a transmission delay line (speed of propagation is less than C). The tube consists of a glass tube wound with a fine, evenly spaced copper helix. The helix is designed so that its natural frequency is in resonance with the loop of the transmitter. The tube is coupled with the transmitter when it is placed in close proximity with the transmitter loop. Powerful resonant waves are set up on the standing wave tube. The waves consist of a series of voltage and current nodes and anti-nodes. (Current antinodes are approximately at voltage nodes, and vice versus). The distance between a pair of anti-nodes (about 11 cm) is 1/2 the wavelength. The waves are exactly similar to the stationary waves in an open-ended organ pipe. Eight to ten stationary waves can be detected with a fluorescent (or neon) tube, or with an incandescent bulb. Moving the fluorescent tube along the length of the Seibt Tube will cause the fluorescent tube to glow at current nodes (current is minimum; voltage is maximum). Moving the incandescent bulb will cause the lamp to glow at voltage nodes (current is maximum; voltage is minimum). In this case, the person holding the bulb is grounded, and a significant high-frequency current passes through both the lamp and the person to ground. (The fluorescent or neon tubes are more visible than the incancescent bulb).

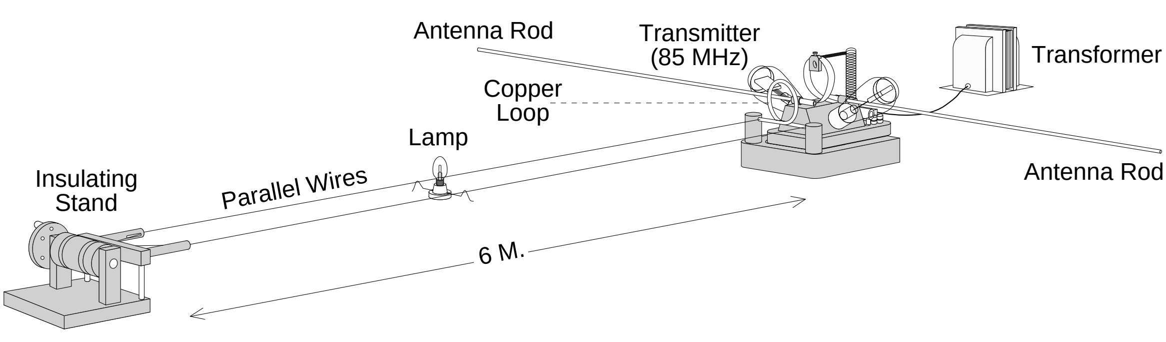


ELECTROMAGNETIC OSCILLATIONS.

D+5+14

Standing waves on two parallel wires, with D+5+10 transmitter.

This is the 'Lecher ' wire method of measuring wavelength.The radio transmitter is a high frequency vacuum tube oscillator with a fixed frequency of 85 MHz, powered by a transformer. (See D+5+10,D+5+12). The transmitter loop is placed close to a second loop of copper rod. On either end of the second loop are attached two long (6M.) parallel wires which stretch out across the lecture table and are secured at the end by an insulating stand. The transmitter loop couples with the second loop, inducing standing radio waves on the long wires. The waves become very pronounced if the length of the wires bears a definite relation to the wavelength. When the ends of the wires are 'open' (held by an insulator), a reversal in phase takes place on reflection, as in an open organ pipe; the open ends become points of maximum potential variation (and minimum current). If the ends are 'closed', or connected by a wire, the potential variation at the ends becomes zero; thus they are potential nodes (and current is maximum.). A small incandescent bulb with wires attached is used to 'tune' the system to resonance. The lamp glows brightly when at the potential antinodes (large potential difference; zero current), and dims when at the potential nodes (regions of zero potential difference; large current). The other potential nodal points on the wires can be located by moving the lamp down the wires. The distance between nodes is half the wavelength. Note: The distance between nodes, when last measured, was .93 M., which is half what it should be. Thus it appears that the oscillator is operating at both 85 and 170 MHz (a harmonic). C = wavelength x frequency.

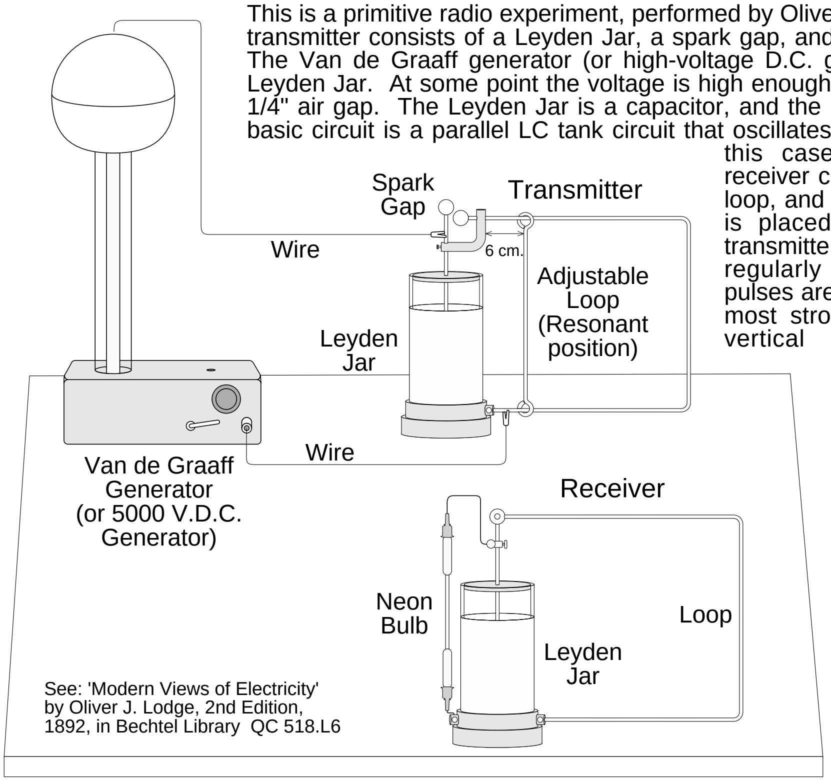


ELECTROMAGNETIC OSCILLATIONS. D+5+16

Lodge's experiment: Spark gap radio transmitter and receiver.

This is a primitive radio experiment, performed by Oliver Lodge in the 1890's. The transmitter consists of a Leyden Jar, a spark gap, and a tuneable loop of metal. The Van de Graaff generator (or high-voltage D.C. generator) charges up the Leyden Jar. At some point the voltage is high enough so that a spark jumps the 1/4" air gap. The Leyden Jar is a capacitor, and the loop is an inductor,-so the basic circuit is a parallel LC tank circuit that oscillates at a certain frequency (in this case about 2.5 MHz). The receiver consists of a Leyden Jar, a loop, and a neon tube. The receiver is placed about a foot from the transmitter. When the transmitter is regularly sparking, radio wave pulses are picked up by the receiver most strongly when the moveable vertical bar of metal on the transmitter loop is moved to the 'resonant' position. At this point, the neon bulb on the receiver flashes with each spark of the transmitter.

The capacitance of the Leyden Jar is about 2.6 nf. The inductance of the loop is about 1.6 µH. Each spark oscillates at about 2.5 MHz and rapidly decays in about 6 microseconds. The wavelength is about 120 M.

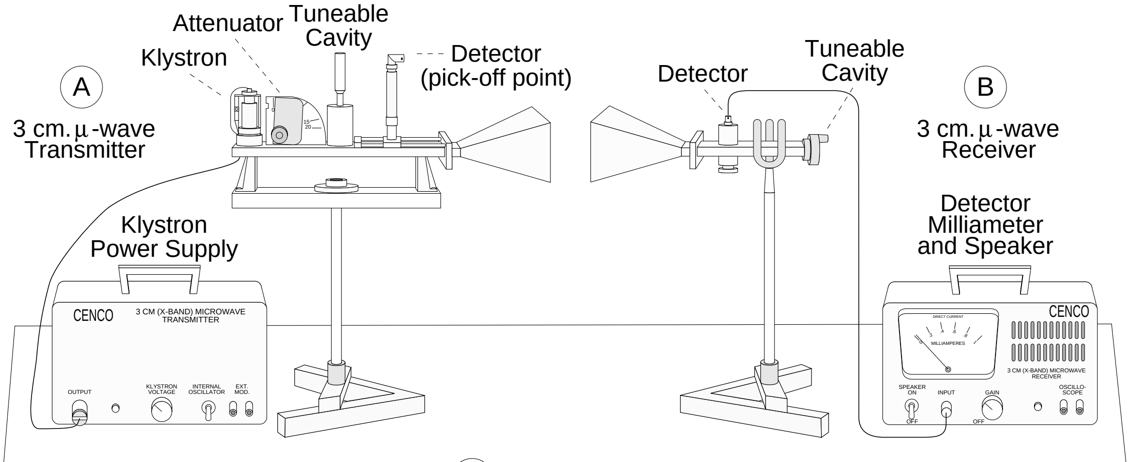


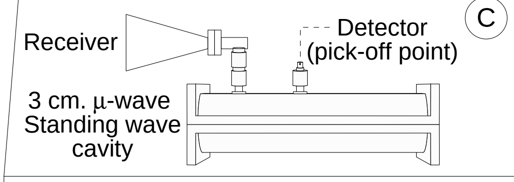
See: 'Modern Views of Electricity'
by Oliver J. Lodge, 2nd Edition,
1892, in Bechtel Library QC 518.L6

ELECTROMAGNETIC OSCILLATIONS. D+5+18

3 cm. microwave klystron oscillator with cavity and waveguides.

In the 'A' transmitter setup , a klystron produces 3 cm. microwaves. There is a tuneable cavity which adjusts the position of the potential nodes and antinodes in the waveguide. A moveable detector on the waveguide can detect the waveguide potential variations (using a milliameter, or the Speaker unit in set-up 'B'). Microwaves from 'A' radiate out and are detected by the receiver of set-up 'B'. The waveguide has a plunger that can be moved forward and backward to tune the cavity.



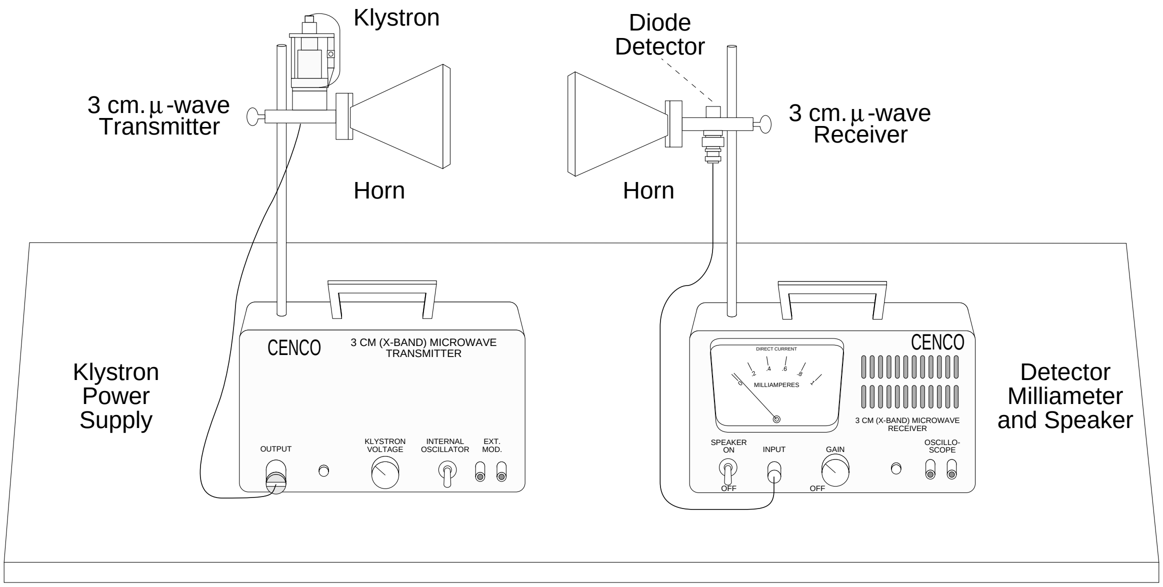


In the 'C' setup, 3 cm. microwaves are funneled into the horn down into the cylindrical cavity, where standing waves are formed. The receiver is moveable, producing different modes (E_{01} and H_{11})and standing wave patterns. The detector is moveable and detects the potential variations in the waveguide.

ELECTROMAGNETIC OSCILLATIONS. D+5+19

3 cm. microwave transmitter and receiver.

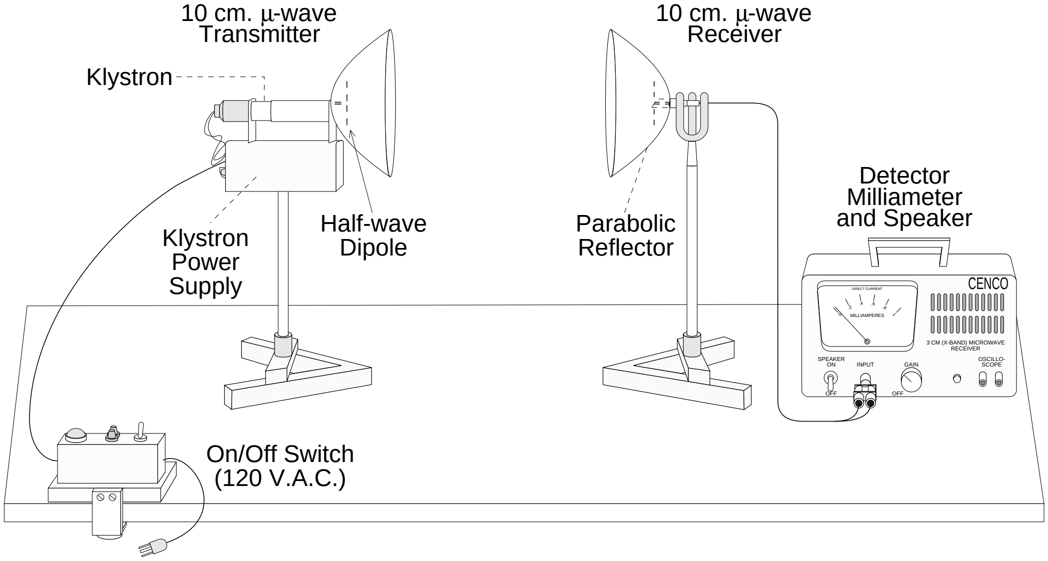
This is a simpler setup than in D+5+18. In the transmitter, power is supplied to a klystron that produces 3 cm. microwaves (polarized) which are radiated out from the horn. In the receiver, microwaves are funnelled into the horn and down the waveguide. The microwaves are detected by a diode, and the signal amplitude can be displayed on the milliammeter, or can be heard as a tone emitted from the speaker.



ELECTROMAGNETIC OSCILLATIONS. D+5+20

10 cm. microwave transmitter and receiver.

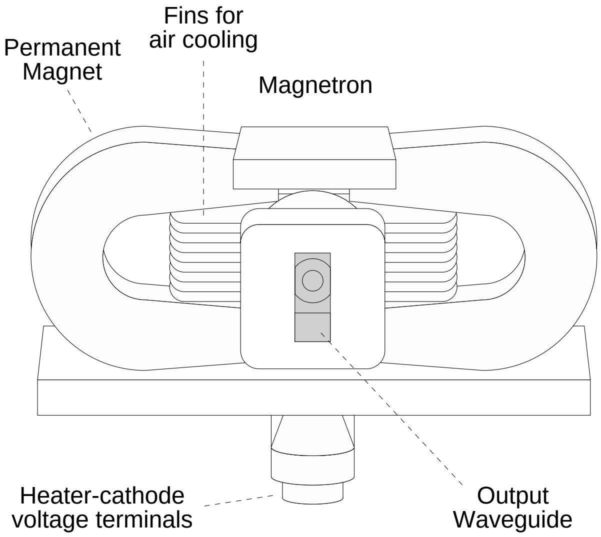
This setup is much like D+5+19, except that the transmitter emits microwaves of 10 cm. wavelength. In the transmitter, power is supplied to the klystron which is a cavity oscillator (the cylindrical tube). A wire loop couples the inner cavity directly to the half-wave antenna at the focus of the parabolic reflector. The paraboloid is a quarter-wave in focal length. The microwaves are sent in a collimated beam to the receiver. The half-wave antenna of the receiver is coupled to a diode, and the signal amplitude can be displayed on the milliameter, or can be heard as a tone emitted from the speaker.



ELECTROMAGNETIC OSCILLATIONS.

D+5+22

Magnetron assembly to show.



Reference: Mac Graw Hill Encyclopedia of Science and Technology, Vol.10, p 340-343, Physics Library

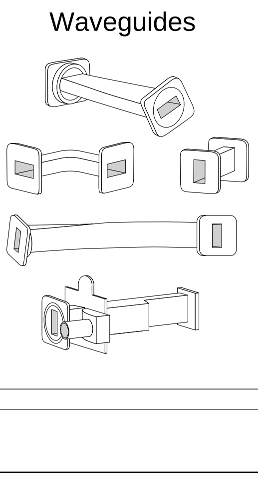
A magnetron is a 'crossed-field' microwave electron tube capable of efficiently generating high-power microwaves (1-100 kW, up to 10 mW for short pulses) in the frequency range of 1-40 GHz. Magnetrons have been used since the 1940s as pulsed microwave radiation sources for radar tracking, for both ground radar stations and aircraft. More recently, they have been used for rapid microwave cooking.

The central portion of the magnetron is cylindrical, with a hollow central cylindrical cathode, and a larger concentric anode. The anode consists of a series of quarter-wavelength cavity resonators placed symmetrically about the axis. Fixed permanent magnets provide a magnetic field parallel to and coaxial with the cathode. A radial DC electric field (perpendicular to the cathode) is applied between anode and cathode. When the cathode is heated, electrons are emitted. The combination of electric and magnetic fields ('crossed-field') causes the electrons to orbit the cathode (moving in a direction perpendicular to both e and b fields). The motion of the swarm of circulating electrons generates electrical noise currents in the surface of the anode, exciting the resonators in the anode so that microwave fields build up at the resonant frequency. The parameters of the tube, especially the velocity of the electrons, have been chosen so that the microwave fields are maximized (by a process called 'electron-bunching'). Thus a relatively small tube can be very efficient. The microwaves exit the magnetron through the output waveguide.

ELECTROMAGNETIC OSCILLATIONS.

D+5+24

Waveguide pieces to show.



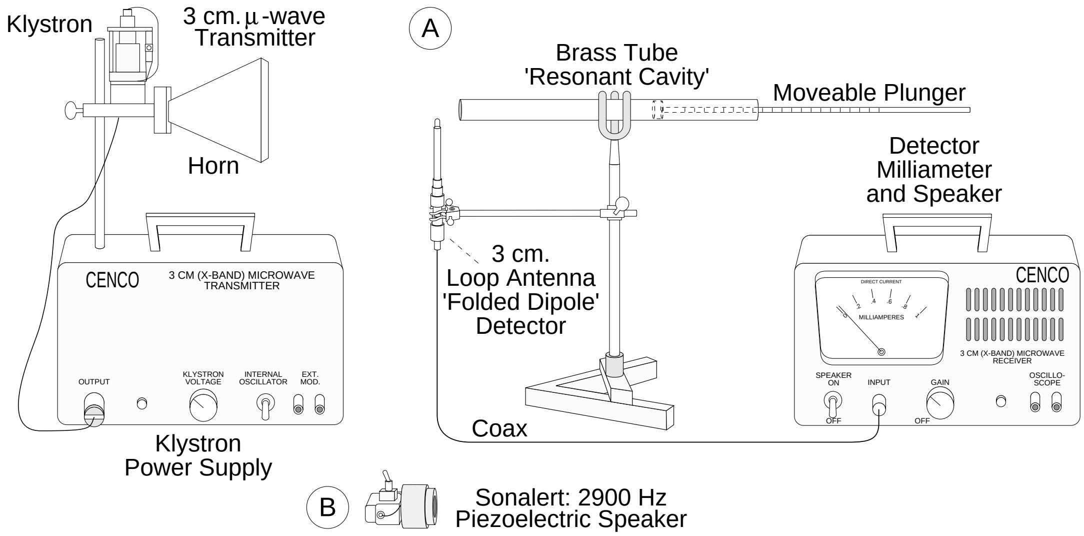
Various types of waveguides to show, most of them designed for 3 cm. wavelength microwaves (100 MHz). Some are straight, some are twisted, some are curved, some are flexible, etc.

ELECTROMAGNETIC OSCILLATIONS. D+5+26

Standing Waves (microwaves or sound waves) in an adjustable cavity.

This is a comparison between standing microwaves and standing sound waves, using the same cavity. In setup 'A', a 3 cm. wavelength microwave transmitter sends 100 MHz microwaves to a 'resonant cavity' brass tube that has a moveable plunger. A 3 cm. loop antenna 'folded dipole', with a detector diode in the base of the handle, is placed near the mouth of the tube. This antenna detects the signal amplitude of the standing wave which can be displayed on the milliameter, or can be heard as a tone emitted from the speaker. As the plunger is moved in and out of the tube, the antenna detects maximums and minimums of the standing microwave.

In setup 'B', most of the equipment is removed. Only the 2900 Hz Sonalert sound source is held by hand in front of the brass tube. The plunger is moved in and out of the tube, and nodes and antinodes can be clearly heard. The wavelength of the Sonalert is about 12 cm.



ELECTROMAGNETIC OSCILLATIONS. D+5+28

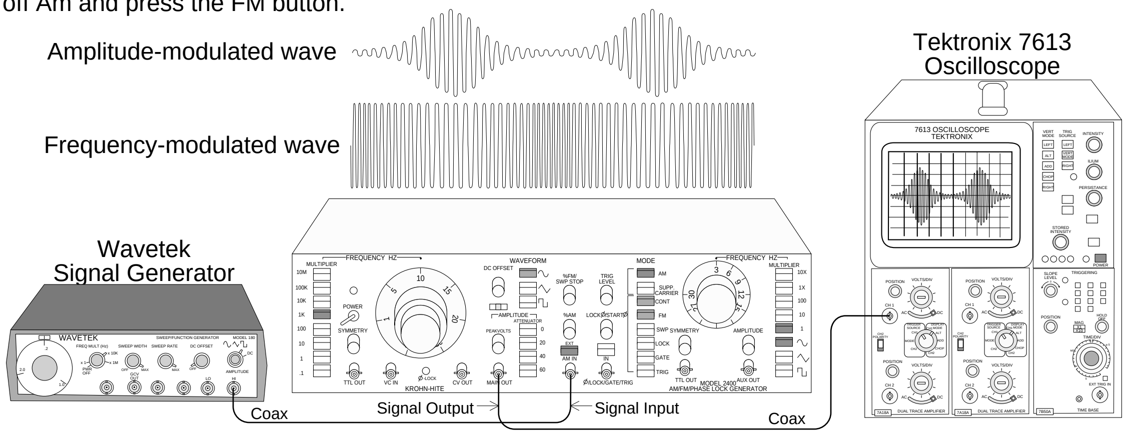
AM and FM Demonstration (minimum 24 hr notice required).

This setup allows one to modify an electronic signal with another. A signal generator feeds a 1 kHz signal into a piece of equipment called an AM/FM/Phase Lock Generator (KH Model 2400). AM or FM modulation options are chosen, and the AM or FM signal is shown on the scope.

Amplitude Modulation (AM) occurs when a varying signal (say from a microphone or signal generator) is used to modulate the amplitude of a carrier wave. The frequency of the carrier wave is much higher than the modulating signal. The amplitude of the carrier wave is made to vary in accordance with the signal wave amplitude, while the frequency of the carrier wave remains unchanged.

Frequency Modulation (FM) occurs when a varying signal is used to modulate the frequency of a carrier wave. The frequency of the carrier wave is made to vary in accordance with the signal wave frequency, while the amplitude of the carrier wave remains unchanged.

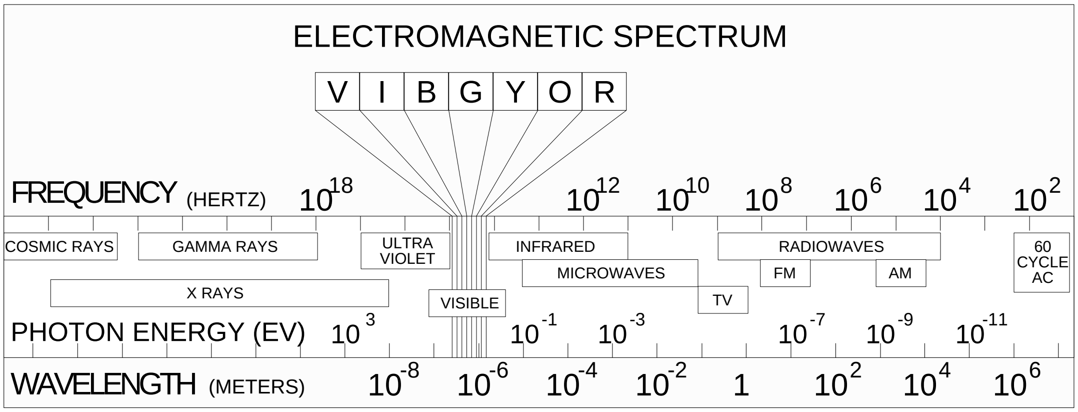
For Setup People: Use Wavetek signal generator 'HI' output, 1 kHz. On the scope, use .5 volts/div., and .1ms time sweep, with external trigger. On the left half of the KH 2400, push the1k multiplier button, choose10 on the dial, and press the sinusoidal waveform button. In the middle of the KH 2400, press the EXT,AM IN button. On the right half of the KH 2400 choose 3 on the dial, and press the 'CONT' button, the 1 multiplier button, and the sinusoidal button. Then, to see AM, press the AM button. To see FM, take off Am and press the FM button.



ELECTROMAGNETIC OSCILLATIONS.

D+5+30

Wall chart of the electromagnetic spectrum.



This is a large chart, about 2'x6'

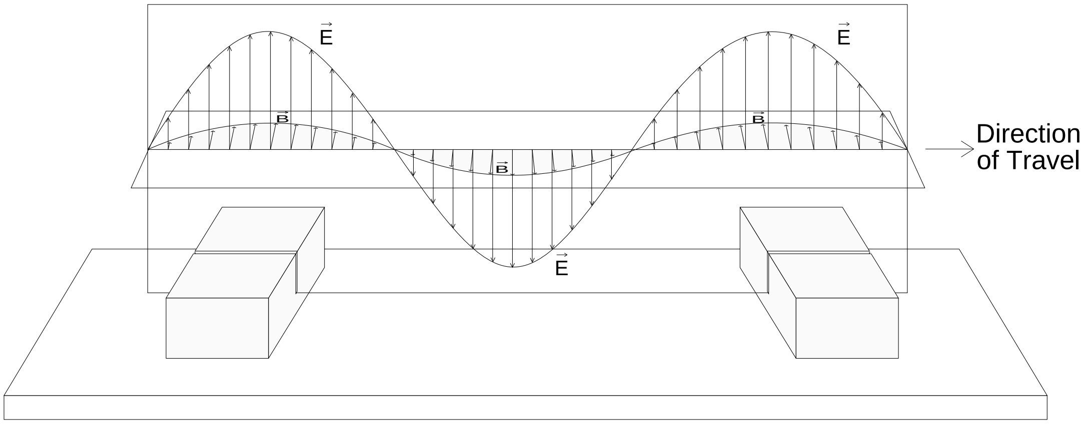
ELECTROMAGNETIC OSCILLATIONS.

D+5+32

Plexiglass model of electromagnetic wave.

This model shows electric and magnetic field strengths in an electromagnetic wave. 'E' and 'B' are at right angles to each other. The entire pattern moves in a direction perpendicular to both E and B.

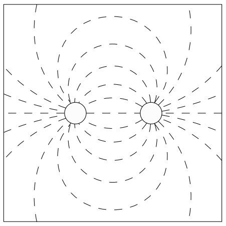
Electromagnet Wave Model (Plexiglass)



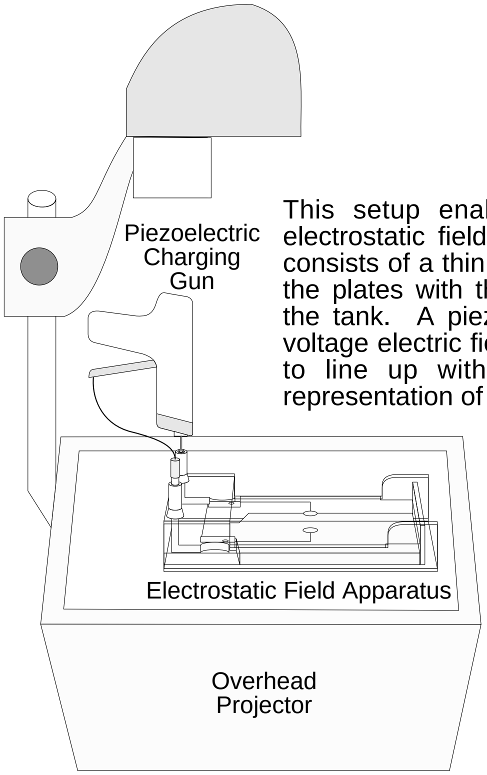
ELECTROSTATICS.

D+10+0

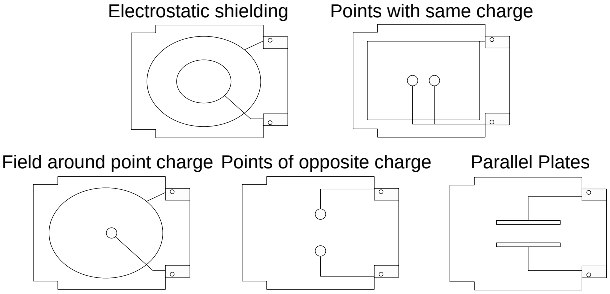
Electric fields: Lines of force shown on an OHP.



Projected Image



This setup enables one to see the lines of force in various electrostatic field configurations. The bottom part of the apparatus consists of a thin tank of silicon oil, glycerol, and wood chips. One of the plates with the desired electrode configuration is inserted over the tank. A piezoelectric charging gun creates a temporary high-voltage electric field between the electrodes, causing the wood chips to line up with the electric field vectors. (This is a visual representation of the Teledeltos experiment performed in the labs.)



Plexiglass plates with metal electrodes in various configurations

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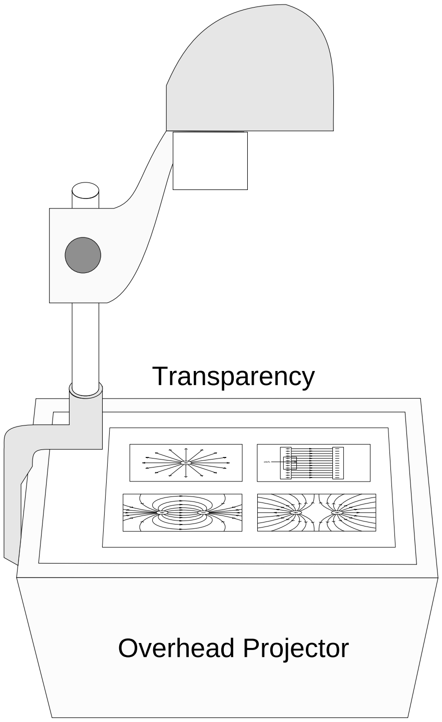
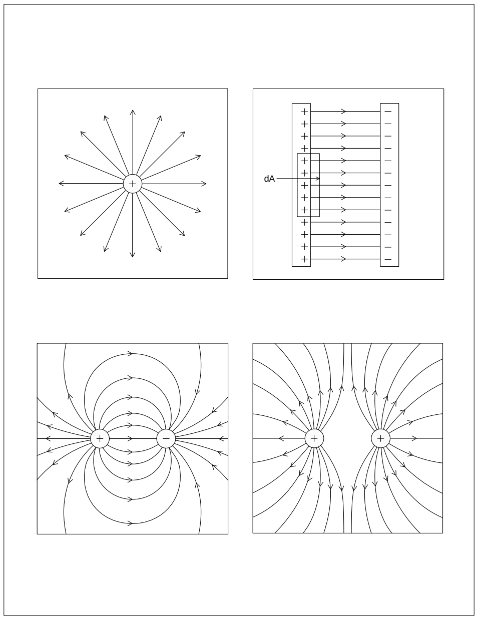
ELECTROSTATICS.

D+10+2

Transparency: Mapping of an electric field.





A transparency showing the mapping of the electric fields for four different situations:

1. A single positive charge.
2. A positive plate and a negative plate.
3. A positive charge and a negative charge.
4. Two positive charges.

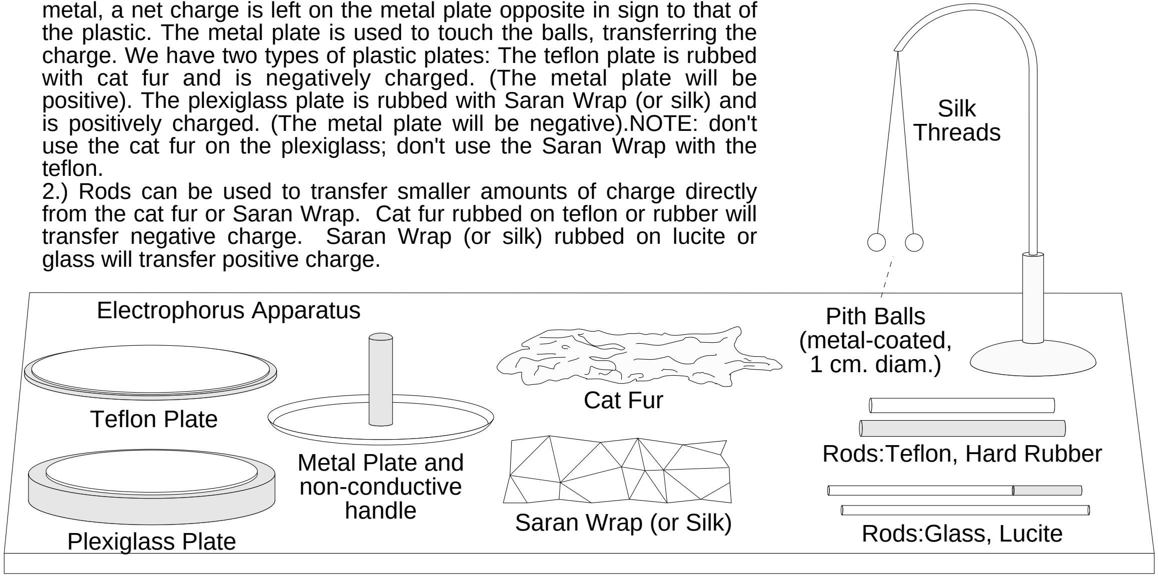
ELECTROSTATICS. D+10+4

Pith balls on thread, with positive and negative charged rods.

In this setup, two metal-coated pith balls (1 cm. diam.) are suspended on non-conducting silk threads. The balls can be charged with positive or negative charge. When both balls have the same charge, they repel each other. The balls can be charged up in several different ways:

1.) A large charge can be delivered to both balls using the 'electrophorous'. This consists of two parts: a piece of plastic that can be charged by friction; and a round metal plate with curved edges and a non-conductive handle. The metal plate is placed on the charged plastic surface, and the front and back metal surfaces are charged by induction. By touching the back surface of the metal, a net charge is left on the metal plate opposite in sign to that of the plastic. The metal plate is used to touch the balls, transferring the charge. We have two types of plastic plates: The teflon plate is rubbed with cat fur and is negatively charged. (The metal plate will be positive). The plexiglass plate is rubbed with Saran Wrap (or silk) and is positively charged. (The metal plate will be negative).NOTE: don't use the cat fur on the plexiglass; don't use the Saran Wrap with the teflon.

2.) Rods can be used to transfer smaller amounts of charge directly from the cat fur or Saran Wrap. Cat fur rubbed on teflon or rubber will transfer negative charge. Saran Wrap (or silk) rubbed on lucite or glass will transfer positive charge.

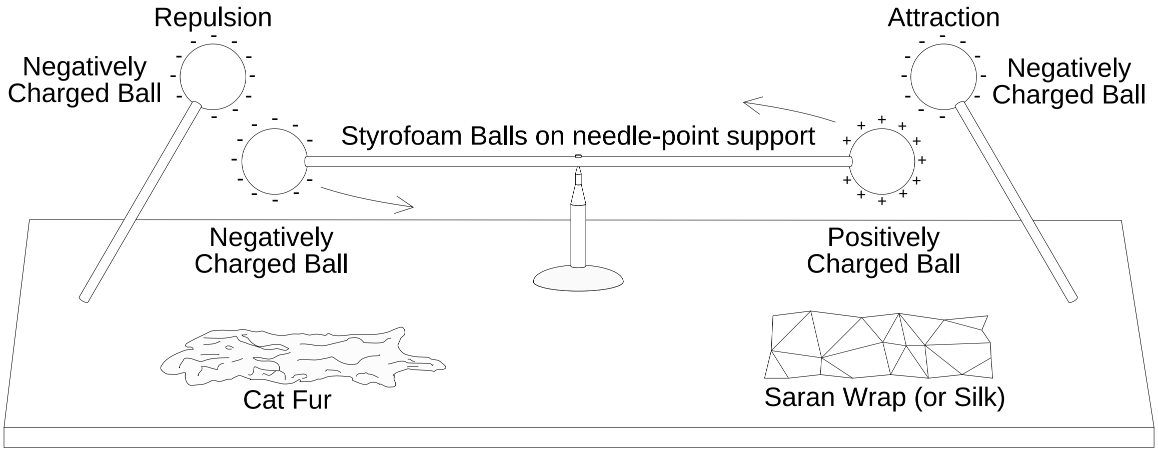


NOTE: A T.V. camera and monitor can be used to show more clearly the separation of the pith balls. Also, a point source light can be used to cast an enlarged shadow of the pith balls on a screen.

ELECTROSTATICS. D+10+6

Attraction and repulsion of charged styrofoam balls.

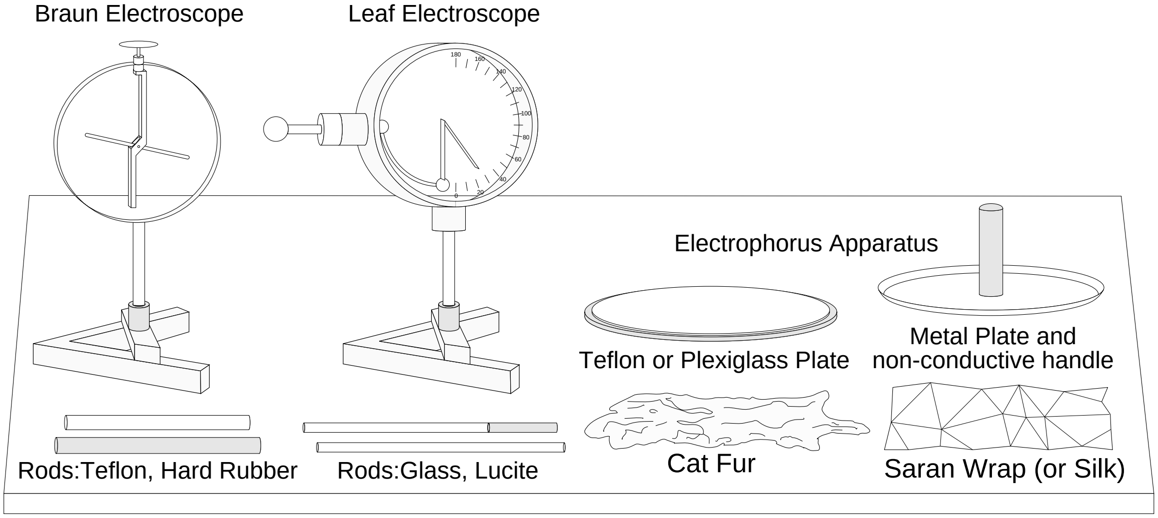
Two Styrofoam balls are balanced on a needle-point support. Cat fur rubbed on one ball will impart a negative charge. Saran Wrap rubbed on the other ball will impart a positive charge. Two other Styrofoam balls on sticks can be charged positively or negatively. A ball-on-stick charged negatively will repulse a negatively charged ball on the needle-point support, causing the support to rotate away. A negative ball-on-stick will attract the positively charged ball on the needle-point support, rotating the assembly toward it.



ELECTROSTATICS. D+10+8

Braun and Leaf electroscopes.

There are two types of electroscopes to show. The Braun electroscope has a light-weight metal pointer on a needle-point suspension. Touching the top metal disk with a charged object causes the pointer to move to a position proportional to the amount of charge applied. The Leaf electroscope has a delicate metallic leaf on a hinge, enclosed in a glass-sided metal housing. Touching the ball of the electroscope with a charged object causes the leaf to rise. The Braun electroscope is adequate for most situations, but is somewhat less sensitive than the leaf electroscope. Charged rods or the electrophorus apparatus can be used to charge either electroscope. See D+10+4 for more information.

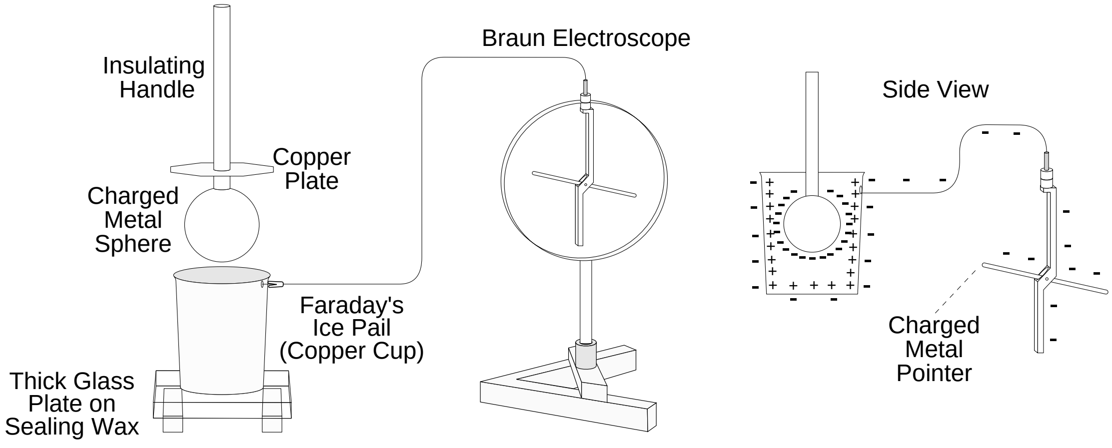


ELECTROSTATICS. D+10+10

Reference: The below was paraphrased from
MODERN COLLEGE PHYSICS, p.343
by Harvey E. White, 6th edition

Faraday's ice pail: Charge induced on the outside of a pail.

The distribution of charge over a metal conductor can be demonstrated by Faraday's Ice Pail. A metal sphere is electrostatically charged. (The Wimshurst machine gives a good charge. The electrophorous works less well. See D+10+18-22) Say the sphere is charged negatively. The metal sphere is then lowered into a metal cup, without actually touching the sides of the cup. Free electrons in the metal pail are repelled to the to the outer surface. The net charge on the outer surface is negative, and the electroscope leaf rises. The charge on the inner surface of the cup is positive. If the ball is now removed, the electroscope leaf falls, and the pail is uncharged. If, however, the ball touches the pail, all negatives leave the ball and neutralize an equal number of pail positives. The electroscope leaf remains fixed in its raised position, showing there is no redistribution of the negative charges on the outer pail surface; and also the number of induced positive charges within the pail equals the number of negative charges on the ball.

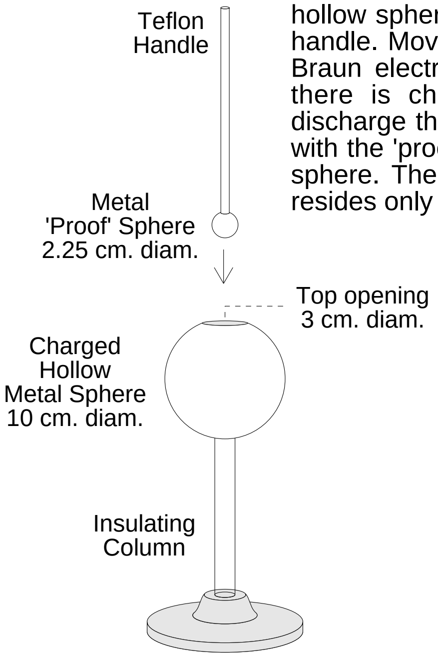


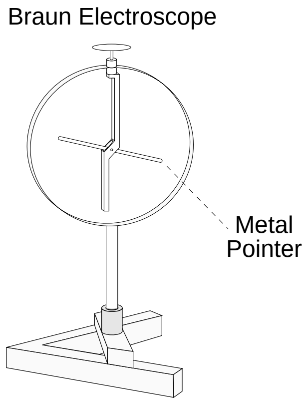
ELECTROSTATICS.

D+10+12

Charge resides on the outside of a conductor.

The large hollow metal sphere is electrostatically charged. (The Wimshurst machine gives a good charge. The electrophorous works less well. See D+10+18-22) Touch the outer surface of the hollow sphere with the small 'proof' sphere mounted on the Teflon handle. Move the small sphere to touch the top metal plate of the Braun electroscope. The metal pointer will move, indicating that there is charge on the outside of the hollow sphere. Now, discharge the electroscope. Touch the inside of the hollow sphere with the 'proof' sphere, then touch the electroscope with the 'proof' sphere. The metal pointer does not move, indicating that charge resides only on the outside of a conductor.

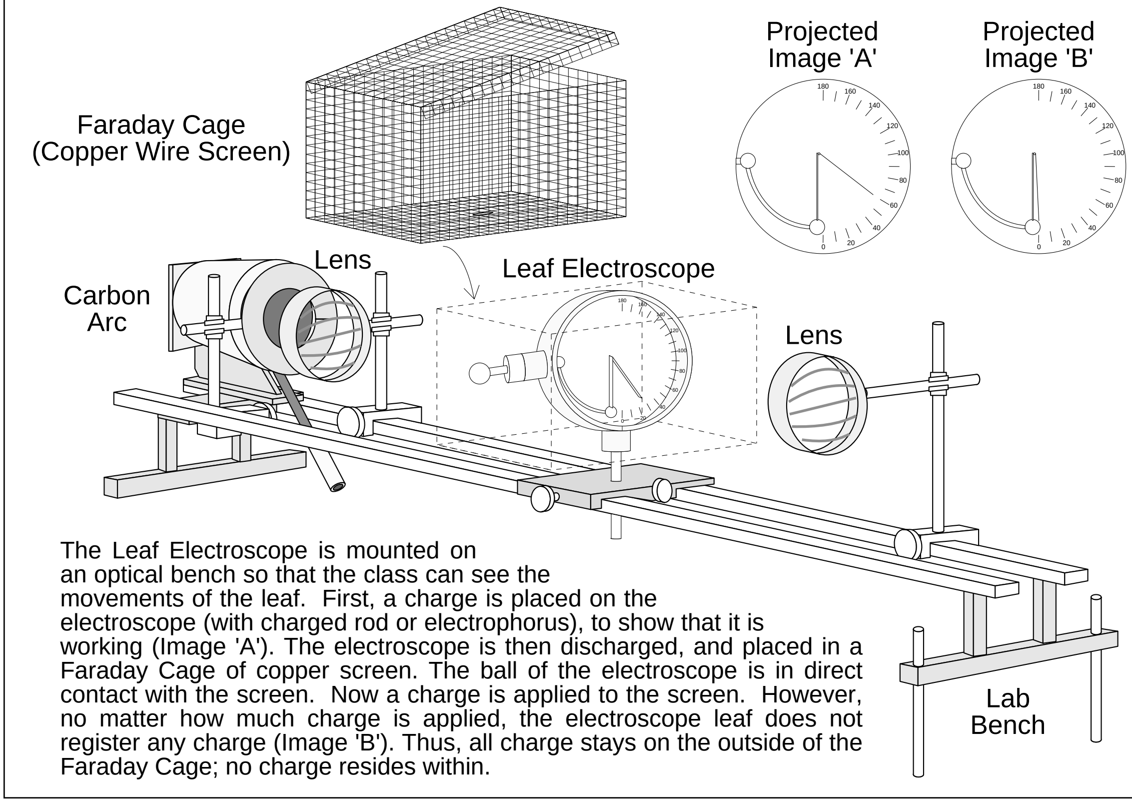




ELECTROSTATICS.

D+10+13

Faraday cage: Enclosed electroscope shows no charge.

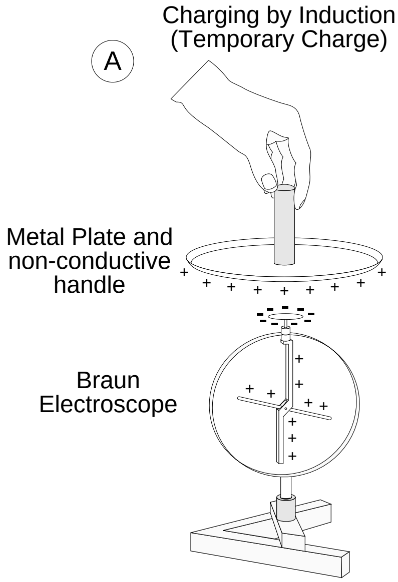


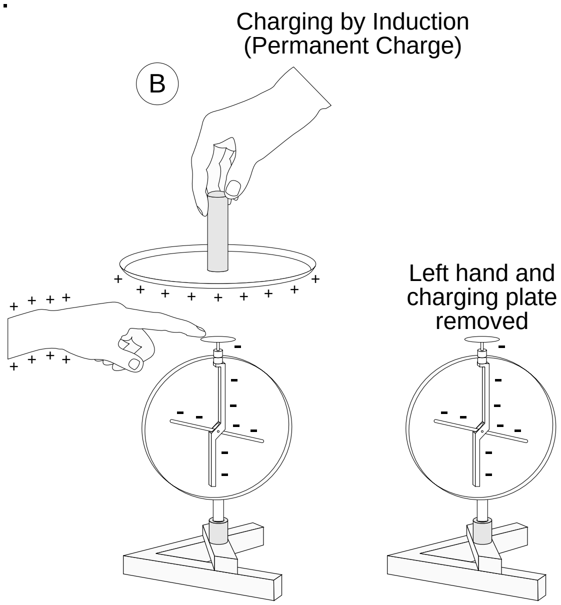
The Leaf Electroscope is mounted on an optical bench so that the class can see the movements of the leaf. First, a charge is placed on the electroscope (with charged rod or electrophorus), to show that it is working (Image 'A'). The electroscope is then discharged, and placed in a Faraday Cage of copper screen. The ball of the electroscope is in direct contact with the screen. Now a charge is applied to the screen. However, no matter how much charge is applied, the electroscope leaf does not register any charge (Image 'B'). Thus, all charge stays on the outside of the Faraday Cage; no charge resides within.

ELECTROSTATICS.

D+10+14

Charging an electroscope by induction.





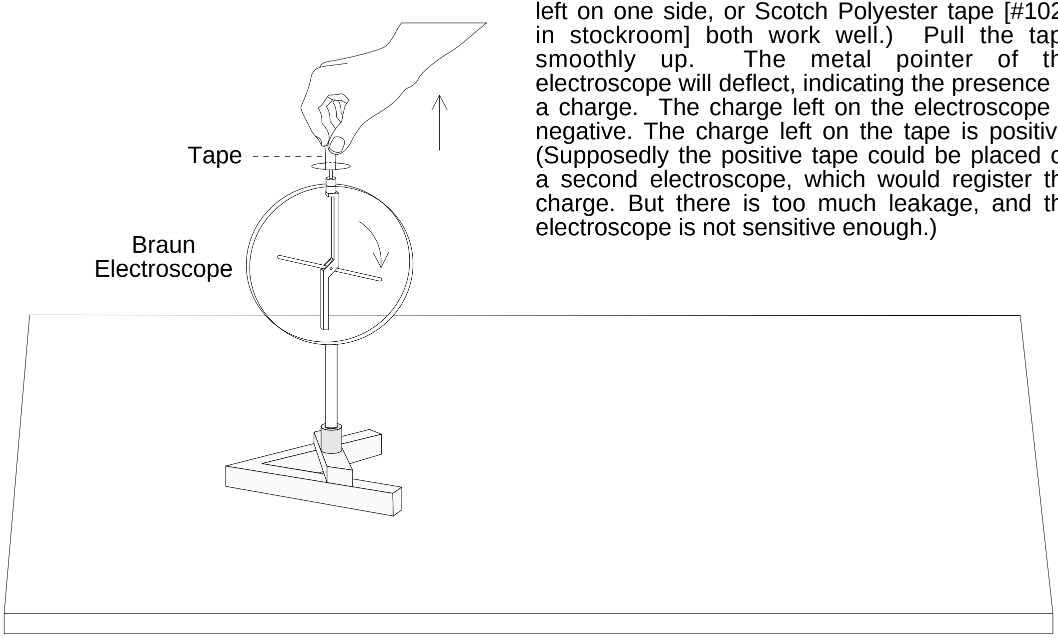
A charged plate (see D+10+18) is brought close to, but not touching, the top plate of the electroscope. The metal pointer deflects. Remove the plate, and the pointer returns to its discharged position. The charged plate displaces free electrons in the electroscope. If the plate is positive, electrons are temporarily drawn from the pointer into the top disk, and a positive charge temporarily results in the pointer, as long as the charged plate is in position.

The top disk of the electroscope is touched by a finger. At the same time a charged plate is brought nearby (but not touching). The finger is withdrawn, then the charged plate is withdrawn. The electroscope will be left with a charge whose sign is opposite that of the charged plate. If the plate is positive, positive charges are repelled into the hand touching the top disk, and negative charges are drawn into the pointer and top disk. Removing the hand leaves the pointer negatively charged.

ELECTROSTATICS.

D+10+16

Separation of charge in electrical tape.

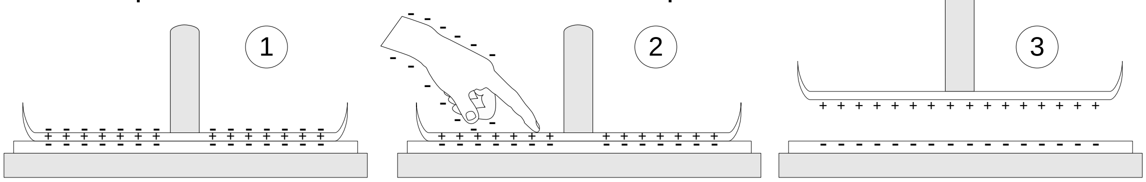


Press a short piece of tape onto the top disk of the Braun Electroscope so that it is very well stuck. (Scotch double-stick foam tape with the wrapper left on one side, or Scotch Polyester tape [#1022 in stockroom] both work well.) Pull the tape smoothly up. The metal pointer of the electroscope will deflect, indicating the presence of a charge. The charge left on the electroscope is negative. The charge left on the tape is positive. (Supposedly the positive tape could be placed on a second electroscope, which would register the charge. But there is too much leakage, and the electroscope is not sensitive enough.)

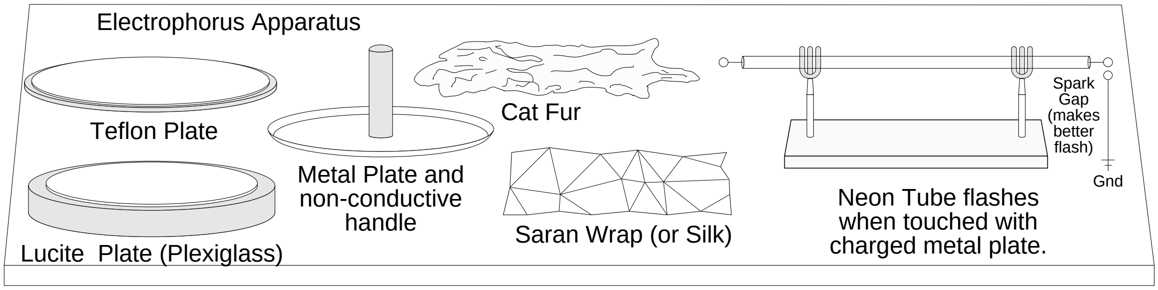
ELECTROSTATICS.

D+10+18

Electrophorous: Cat fur on teflon, Saran Wrap on lucite.



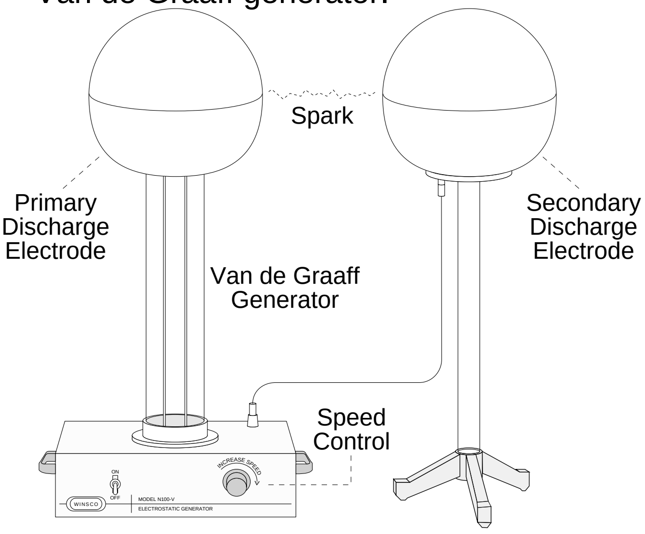
The 'electrophorous' consists of two parts: a piece of non-conductive plastic that can be charged by friction; and a round metal plate with curved edges and a non-conductive handle. We have two types of plastic plates: The teflon plate is rubbed with cat fur and becomes negatively charged. The lucite plate (plexiglass) is rubbed with Saran Wrap (or silk) and becomes positively charged. The metal plate is then placed on the charged plastic insulating surface, and the top and bottom metal surfaces are charged by induction. By touching the top surface of the metal, a net charge is left on the metal plate opposite in sign to that of the plastic. The metal plate can now be used to transfer charge. The charge can be discharged into an electroscope, or into a neon tube (causing a brief flash). For example, when cat fur is rubbed on the teflon, the top surface of the teflon becomes negatively charged. Placing the metal plate on the charged teflon causes electrons in the metal to be repelled by induction to the top of the metal plate; and the bottom of the metal becomes positive. Touching the top surface of the metal plate drains off electrons, and the plate, when lifted, has a net positive charge. NOTE: don't use the cat fur on the plexiglass; don't use the Saran Wrap with the teflon.

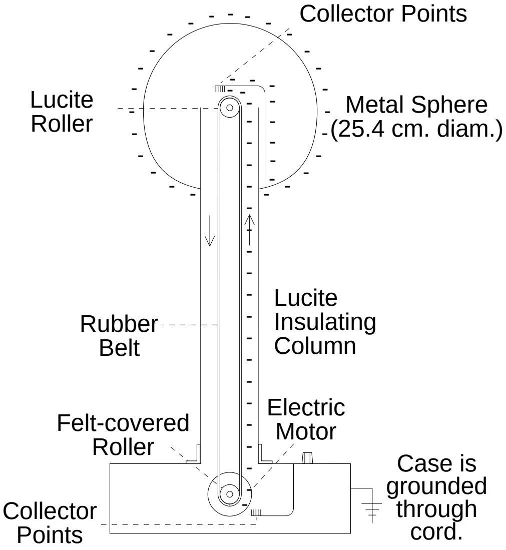


ELECTROSTATICS.

D+10+20

Van de Graaff generator.





This Van de Graaff apparatus is an electrostatic generator capable of throwing sparks 25 to 38 cm. long from the primary electrode to a secondary discharge electrode (depending on humidity, motor speed,etc.) The apparatus is safe, delivering at most a 10 microamp current.

A large hollow conducting aluminum sphere is supported on top of a tall insulating lucite column above a metal base. The sphere is charged to a high potential (250K-400K volts) by a moving nonconducting rubber belt. In the base, the felt-covered roller, pressing against and separating from the rubber belt, causes negative charge to be left on the rubber belt as it travels upward. When the belt reaches the top and rolls over the lucite roller, the negative charge jumps to sharp collector points and is transferred immediately to the outer surface of the metal sphere. As more charge is brought upward, the sphere becomes more highly charged and reaches greater voltage. The process requires energy, since the upward moving charged belt is repelled by the charged sphere. The energy is supplied by the motor driving the belt.

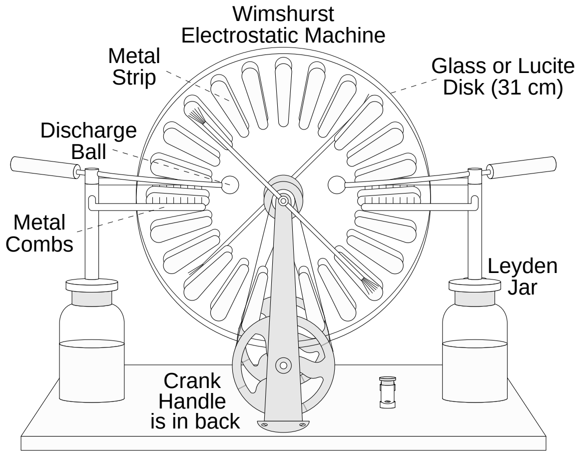
ELECTROSTATICS. D+10+22

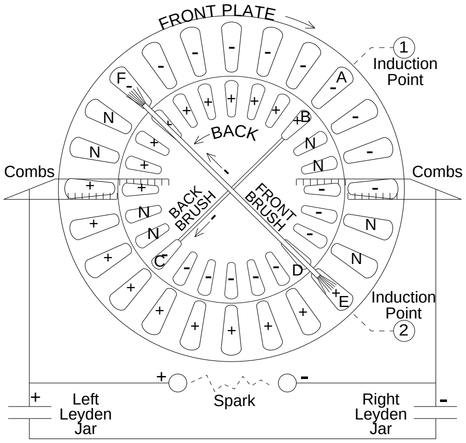
Wimshurst machine, large or small.

The Wimshurst machine is an electrostatic generator capable of throwing long sparks (10-12 cm, at low humidities) between two discharge balls mounted on swivel arms, when both Leyden jars are connected in the circuit. This generator is different from the Van de Graaff demo in that the electrical charge is generated by induction rather than friction.

The Wimshurst machine consists of two parallel nonconductive plates (lucite or glass), hand driven so that they rotate in opposite directions. Each plate has narrow metal strips arranged radially, equal distances apart around the rim. Two brushes connected to metal rods, one in front and one in back, transfer charge. Metal combs pick up charge and store it in Leyden jars (high-voltage,non-leaky capacitors).

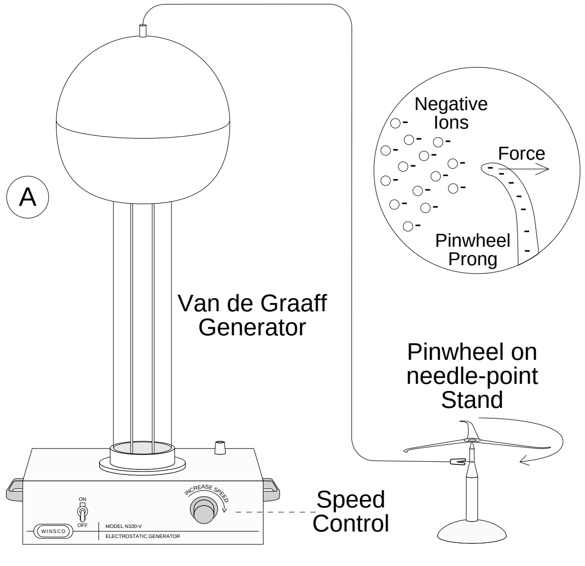
Suppose that metal strip 'A' on the front plate (FP) is negative and has moved clockwise to be opposite strip 'B' on the back plate (BP), at point '1'. 'A' is negative and induces a positive charge on the front side of strip 'B' and a negative charge on the back side of 'B'. The rear brush carries the negative charge from 'B' to strip 'C' on BP,leaving 'B' positive. As BP moves counter-clockwise to point '2', negative strip 'D' on BP induces a positive charge on the back of strip 'E' and a negative charge on the front of 'E' on FP. The front brush carries negative charge from 'E' to 'F' on FP, leaving 'E' positive. Negative charge from both plates is picked up by the 'combs' on the right Leyden jar; positive charge goes to the left Leyden jar. The cycle is now complete. (Points labelled 'N' are non-charged.) When voltage is sufficiently high, sparks jump between the discharging balls.

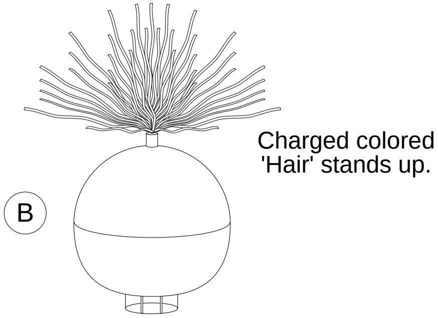


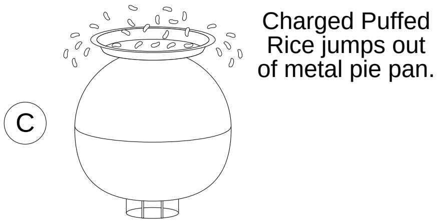


ELECTROSTATICS. D+10+24

Electrostatic pinwheel: Van de Graaff makes pinwheel spin. Plus several others.







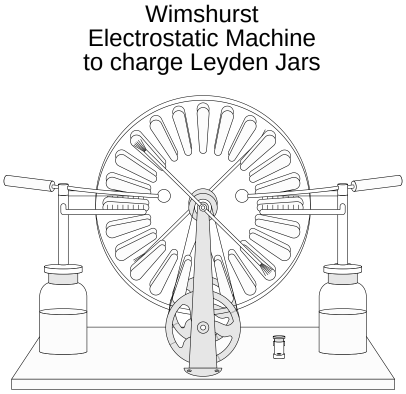
Pinwheel: In 'A', electric charge is transferred via wire from the top metal sphere of the Van de Graaff generator (which is at a high potential) to the metal needle-point stand. On top of the needle point is a three-pronged pinwheel. Charge flows from the stand, through the pinwheel, and is sprayed into the air near each pinwheel prong. The sprayed electrons form a cloud of ions in the air. Each negative pinwheel prong is repelled by its associated negative ion cloud, causing the pinwheel to rotate.

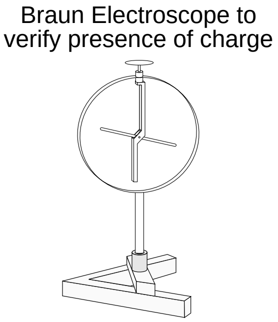
Hair: In 'B', colored strips of paper are fastened to the top metal sphere. (In the old days hair was used). When the Van de Graaff is fully charged, each strip of paper gets negatively charged and repells each other strip. The 'hair' stands up and spreads out.

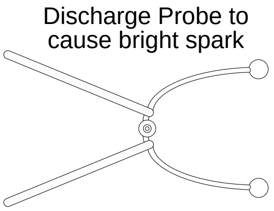
Puffed Rice: In 'C', puffed rice is put in a metal pie pan that connects to the top of the metal sphere. When the Van de Graaff charges up, the negatively charged puffed rice jumps out of the negatively charged pan.

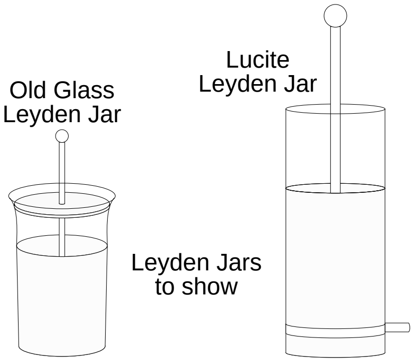
ELECTROSTATICS. D+10+26

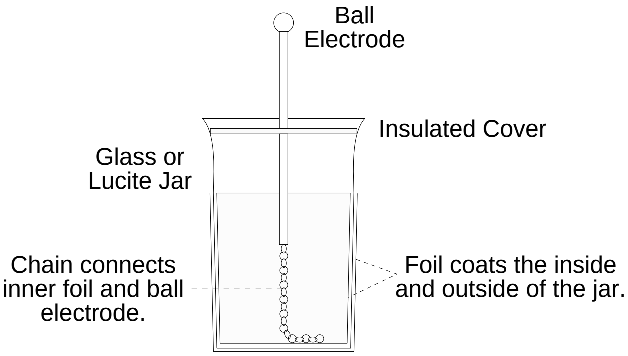
Various Leyden jars to show.







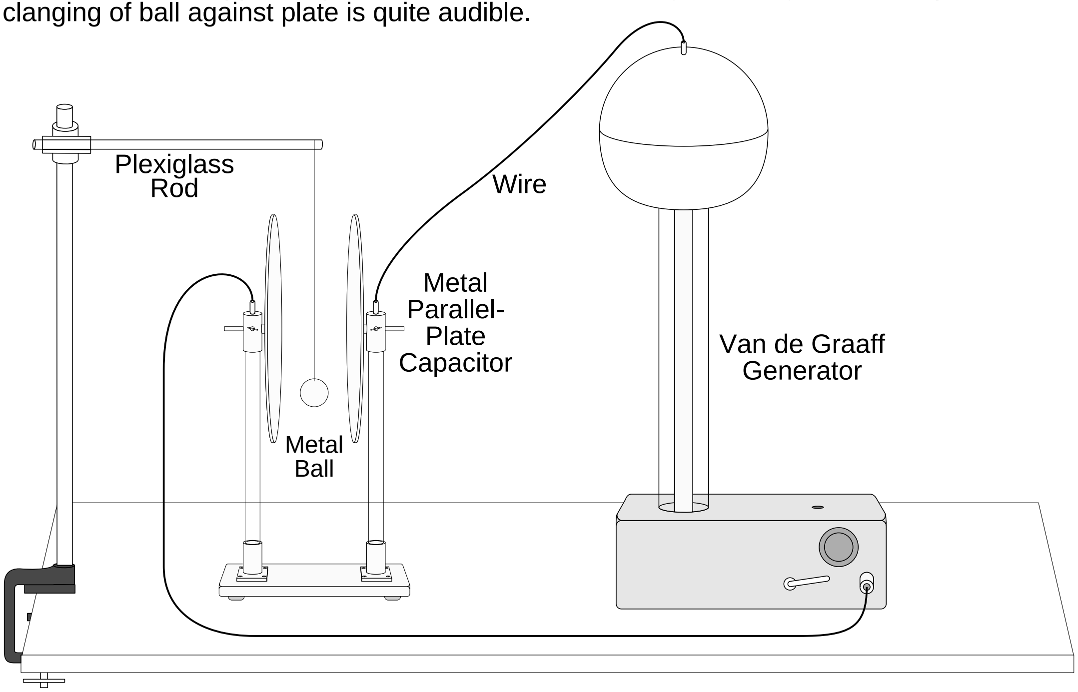




ELECTROSTATICS. D+10+28

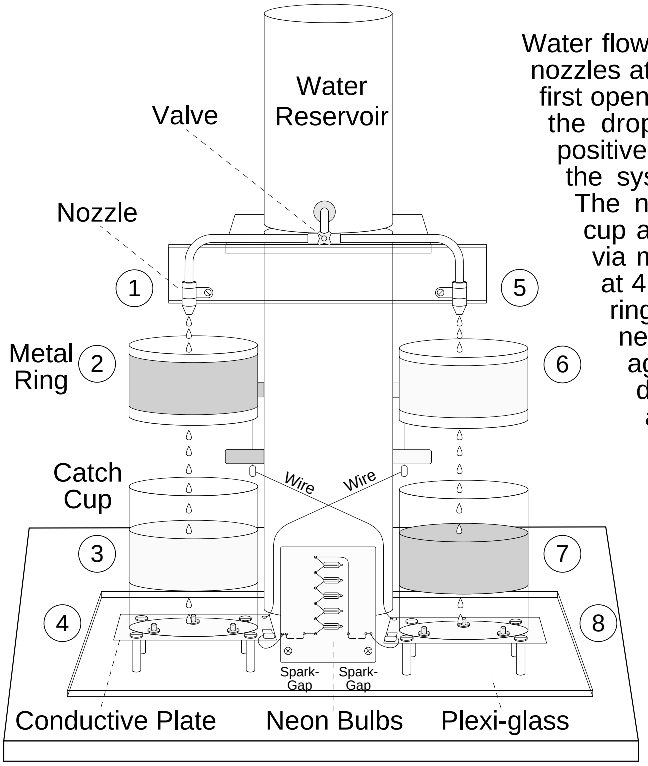
Electrostatic doorbell: Ball bangs between charged plates. (Same as D+0+6)

Negative charge from the Van de Graaf generator builds up on one plate. The metal ball, initially uncharged, is attracted to the negative plate and hits it, becoming negative also. It rebounds to the opposite plate where it loses its charge. The cycle then repeats. The clanging of ball against plate is quite audible.



ELECTROSTATICS. D+10+30

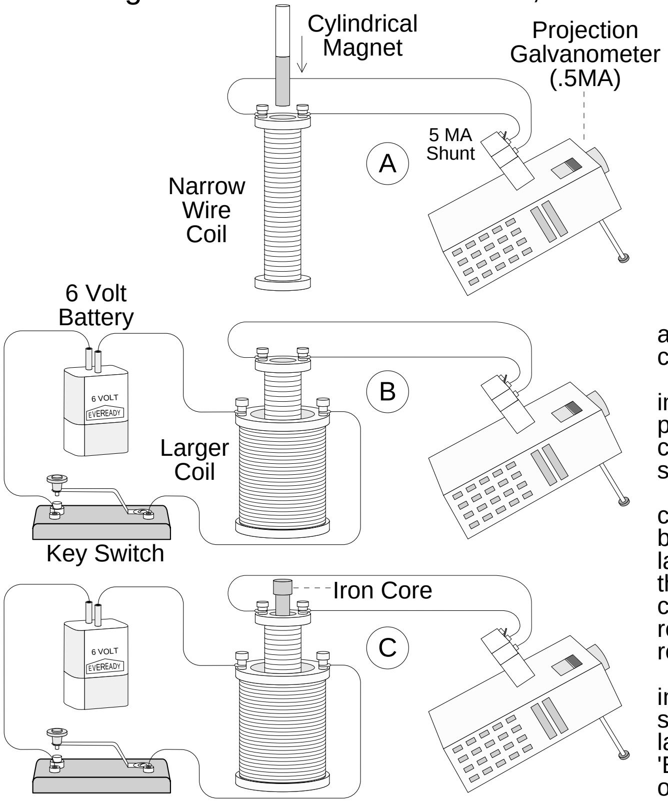
Kelvin water-drop generator: Falling charged water drops light neon bulbs.

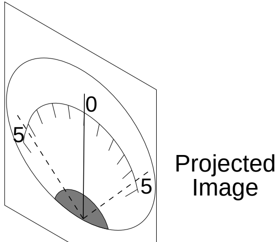


Water flows from a reservoir and drips through two nozzles at points 1 and 5. When the water valve is first opened, the water drop at 1, at the time when the drop separates from the nozzle, is either positive or negative. Say it is negative. To make the system neutral, the drop at 5 is positive. The negative drop lands in the plastic catch cup at 3. The bottom of the cup is connected via metal screws to a conductive metal plate at 4, which is connected by wire to the metal ring at 6. Thus, the ring at 6 becomes more negative, causing the next drop at 5 once again to be positive, by induction. The drops landing in catch cup 7 are positive, and make an electrical connection to the metal ring at 2, making the ring more positive. This causes the next drop at 1 to be negative, by induction. The cycle repeats until a large amount of negative charge is in cup 3, and a lot of positive charge is in cup 7. When enough charge is stored, sparks jump across the two spark gaps, and the bank of neon bulbs flash. There are a lot of flashes before the water reservoir is drained.

FARADAY'S LAW. D+15+0

Bar magnet induces current in a coil, shown on galvanometer.





A changing magnetic field cutting across a coil of wire induces an electric current.

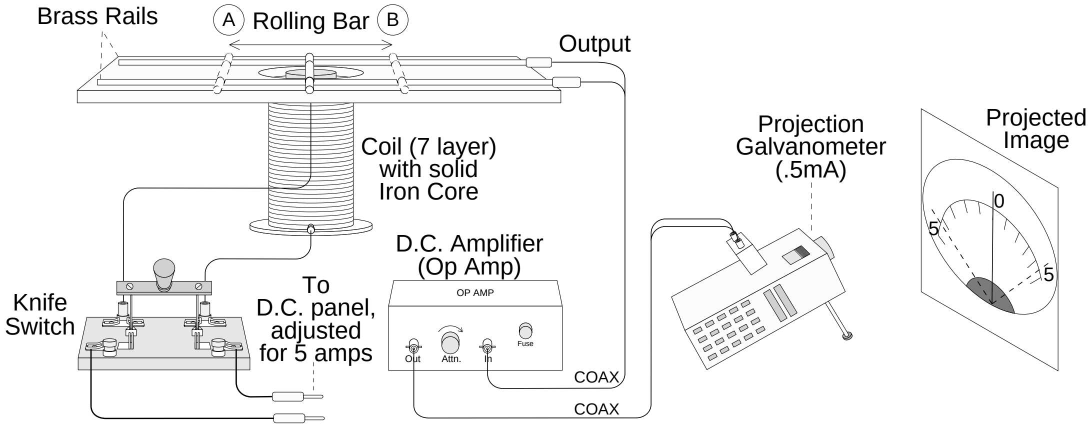
In 'A', a cylindrical bar magnet is thrust into a tall narrow coil which is hooked to a projection galvanometer. The induced current causes the needle to swing full scale in both directions.

In 'B', the narrow coil is placed inside a coil of larger diameter. A 6 volt D.C. battery and key switch are hooked to the larger coil. When the switch is pressed, the surge of magnetic field from the larger coil cuts the narrow coil. A current surge is registered when the switch is pressed or released, smaller than in 'A'.

In 'C', a soft iron cylindrical core is inserted into the narrow coil. When the switch is pressed or released, a much larger current swing is registered than in 'B'. Other cores can be inserted: a bundle of iron wires, a bronze core, and lucite.

FARADAY'S LAW. D+15+2

Elementary generator: Bar moved in magnetic field.

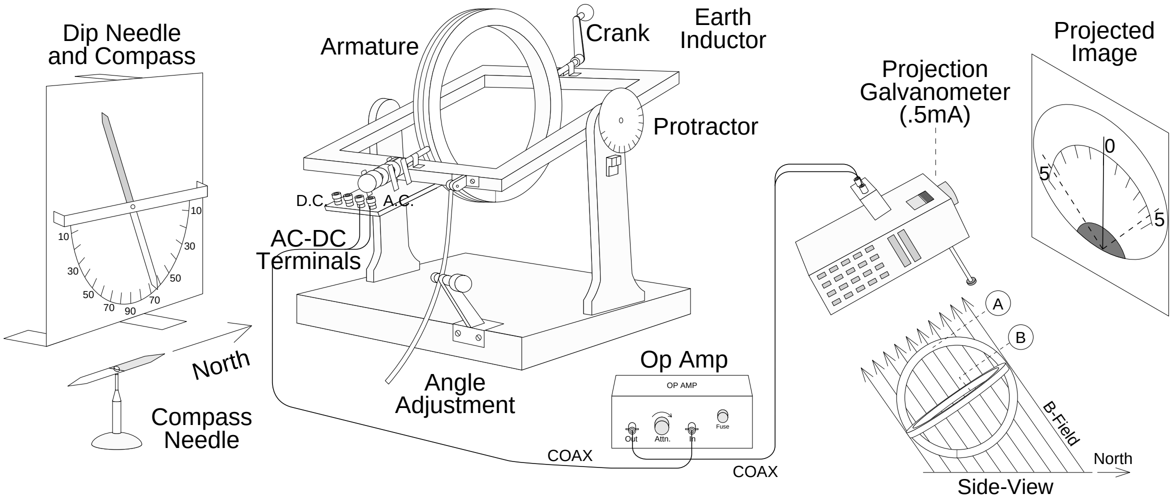


This is a simple generator, illustrating the principle that a changing magnetic field cutting across a loop of wire induces an electric current. Five amps of current (D.C.) are sent through a large coil of wire, with a soft iron core inserted within. A stationary magnetic field is generated, enhanced by the presence of the iron core. A board with two brass rails sits on top of the coil, and another independent brass bar can be moved manually along the rails. The brass bar and rails constitute a conducting 'loop' that cuts across the magnetic field. Even though the magnetic field is stationary, the magnetic field strengths vary at different locations, so essentially a changing magnetic field cuts the loop when the bar is moved. The current generated by moving the bar is amplified by a D.C. Amplifier (Op Amp) and the variations are shown with a projection galvanometer.

The two rails and bar must be polished to insure good conduction. The op amp is set so that a brisk sliding of the bar gives a moderate meter fluctuation. NOTE: whenever the knife switch is opened or closed, the meter will record a strong induced current spike from the building up or collapsing of the magnetic field. If the bar is at position 'A', more of the loop is cut by the flux than at 'B'. Thus a much larger spike (about10 times larger) is produced at 'A' than if the bar were at position 'B'. In order to avoid pegging the galvanometer needle, either have the bar off the rails while opening or closing the switch, or have the bar at 'B'.

FARADAY'S LAW. D+15+4

Earth inductor: Coil spun in Earth's field makes voltage.



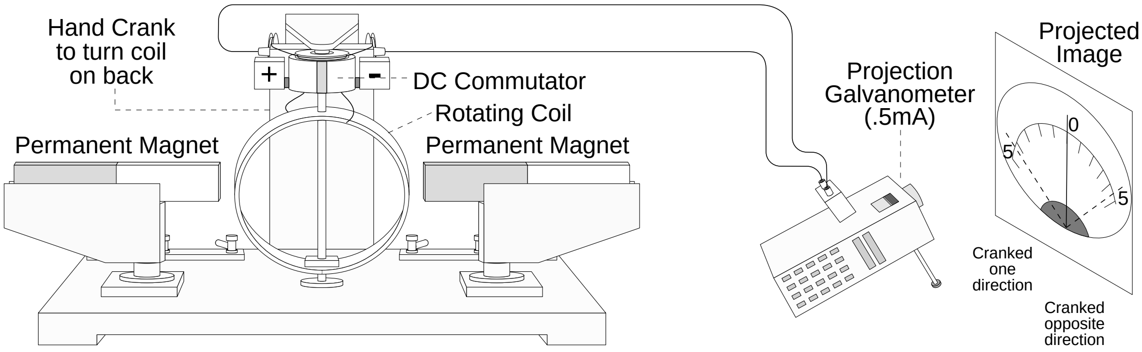
The 'Earth Inductor' is a simple generator, illustrating the principle that a changing magnetic field cutting across a loop of wire induces an electric current. In this case, the magnetic field is that of the earth. A coil of wire is rotated in the earth's magnetic field, generating an emf.

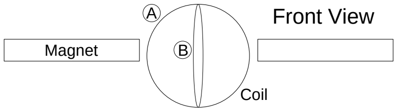
A simple magnetized needle on a stand finds north. Both the dip-needle and inductor apparatus are aligned with north. The dip-needle indicates the angle of the magnetic flux coming up through the earth. The inductor apparatus frame is tilted so that the coil-frame is perpendicular to the Earth's magnetic flux. (I.E.: The frame is rotated from the horizontal by an angle equal to the compliment of the dip-needle angle.) When the coil is rotated, maximum emf is generated at 'A' and min is at 'B' (in the side-view drawing). The apparatus has commutators so that either an AC sinusoidal signal or DC rectified signal can be amplified and visually represented by the projection galvonometer.

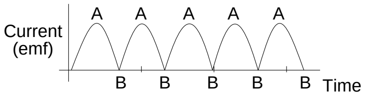
FARADAY'S LAW. D+15+6

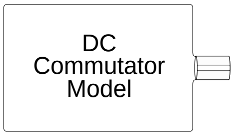
Generator: Coil with DC commutator rotates between magnets.

Simple D.C. Generator









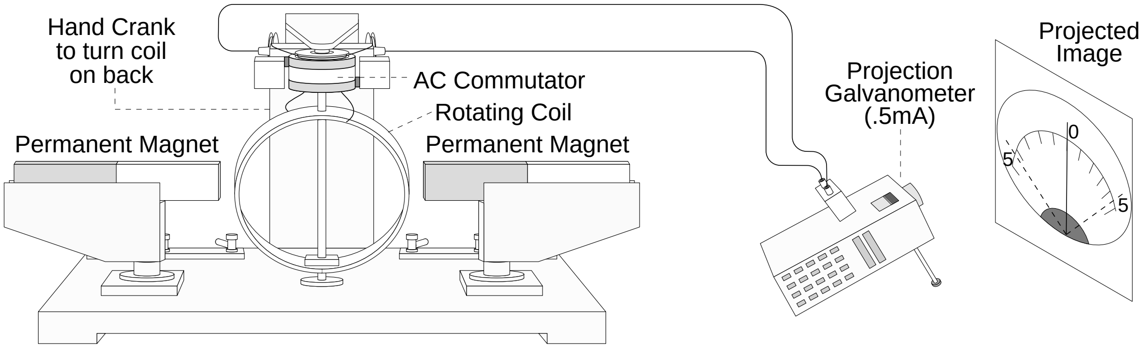
This is a simple generator illustrating the principle that a changing magnetic field cutting across a loop of wire induces an electric current. In this case, the magnetic field is produced by two strong permanent bar magnets mounted in line with each other, on opposite sides of the wire coil; close to the perimeter of the coil. The coil of wire is rotated in this magnetic field, generating an emf. The crank-handle/pulley system is on the back of the apparatus, not visible in this drawing.

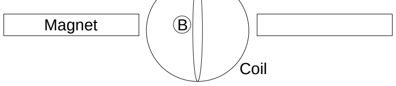
The 'split' commutator causes the output of the generator to be rectified D.C. current in the milliamp range. For example, crank the handle clockwise, and the current will go from 0 to +.5 ma to 0. Crank the handle counter-clockwise, and the current range will be 0 to -.5ma to 0. (Or vice versus.)

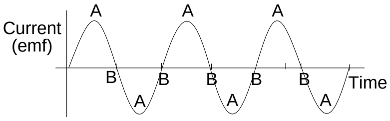
FARADAY'S LAW. D+15+8

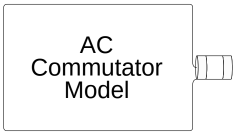
Alternator: Coil with AC commutator rotates between magnets.

Simple A.C. Alternator









This is a simple generator illustrating the principle that a changing magnetic field cutting across a loop of wire induces an electric current. In this case, the magnetic field is produced by two strong permanent bar magnets mounted in line with each other, on opposite sides of the wire coil; close to the perimeter of the coil. The coil of wire is rotated in this magnetic field, generating an emf. The crank-handle/pulley system is on the back of the apparatus, not visible in this drawing.

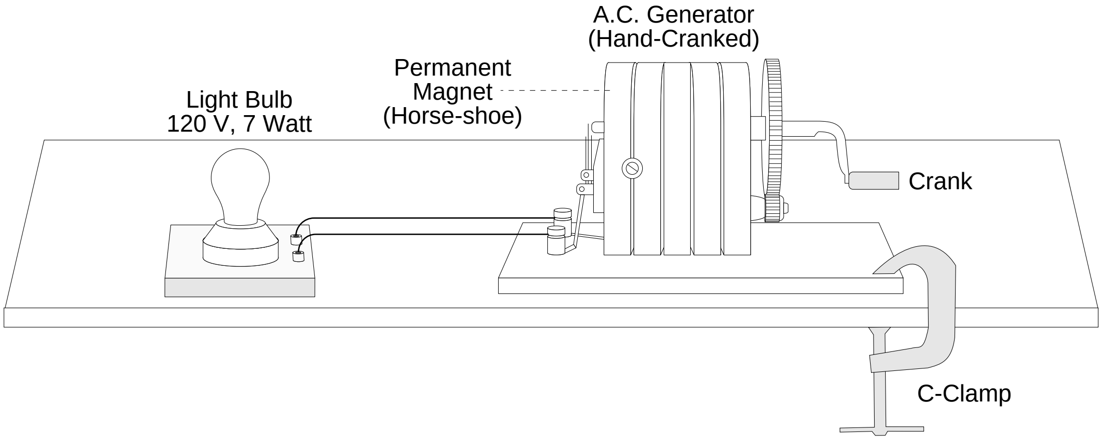
The 'slip-ring' commutator causes the output of the generator to be A.C. current in the milliamp range. For example, crank the handle clockwise or counterclockwise, and the current will go from 0 to +.5 ma to 0 to -.5 ma to 0, etc.

FARADAY'S LAW. D+15+10

Hand-cranked generator powers 12 volt lamp.

This A.C. generator consists of a cylindrical coil of wire that rotates within the stationary field of 5 permanent horse-shoe magnets. A geared hand-driven crank causes the coil to rotate. The rotating coil cuts across the magnetic flux of the horshoe magnets, inducing an emf. Depending on the speed that the generator is cranked, the A.C. voltage may be as high as 80 volts. The light bulb connected to the generator glows brightly.

NOTE: A larger, hand-cranked D.C. generator is also available. A projection voltmeter or ammeter may be introduced into the circuit if desired.

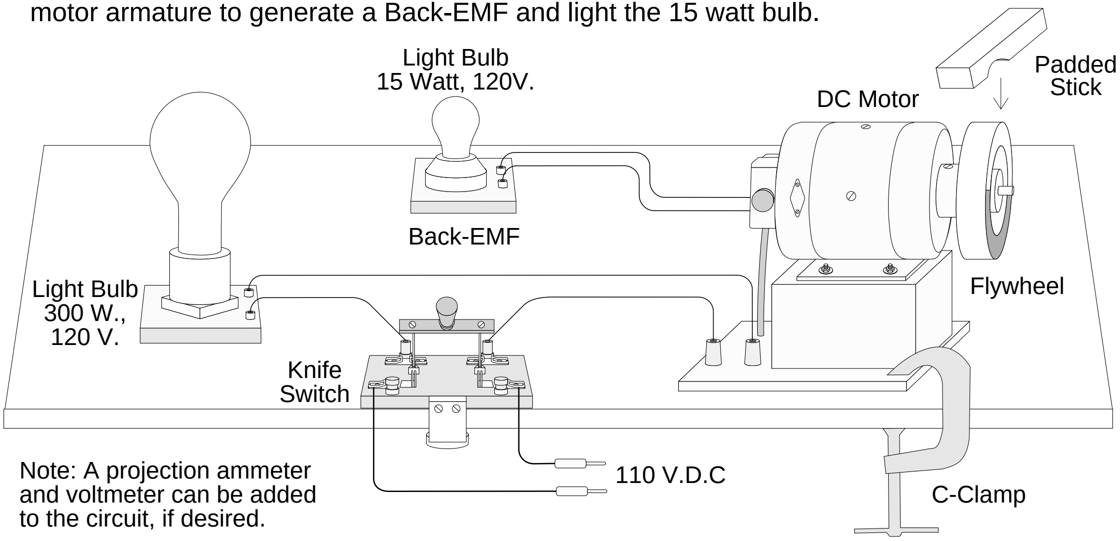


FARADAY'S LAW. D+15+12

Back EMF in a series DC motor with large flywheel.

The DC motor is series-compound, with a special connection to the inner armature coil to demonstrate 'Back-EMF'. When power is first applied, the 300 watt bulb glows brightly at first, then dims as the motor achieves speed. The 15 watt bulb is off at first, then glows brightly as the motor speeds up, indicating the production of Back-EMF. If a padded stick is pressed down on the spinning flywheel, the 300 watt bulb glows more brightly, and the 15 watt bulb dims. If power to the circuit is cut off, the 15 watt bulb continues to glow, becomming dimmer as motor speed drops, and the 300 watt bulb stays off.

Another way to demonstrate Back-EMF is to spin up the motor with a hand-held 'spinner motor' pressed against the flywheel. There is enough residual magnetism in the motor armature to generate a Back-EMF and light the 15 watt bulb.

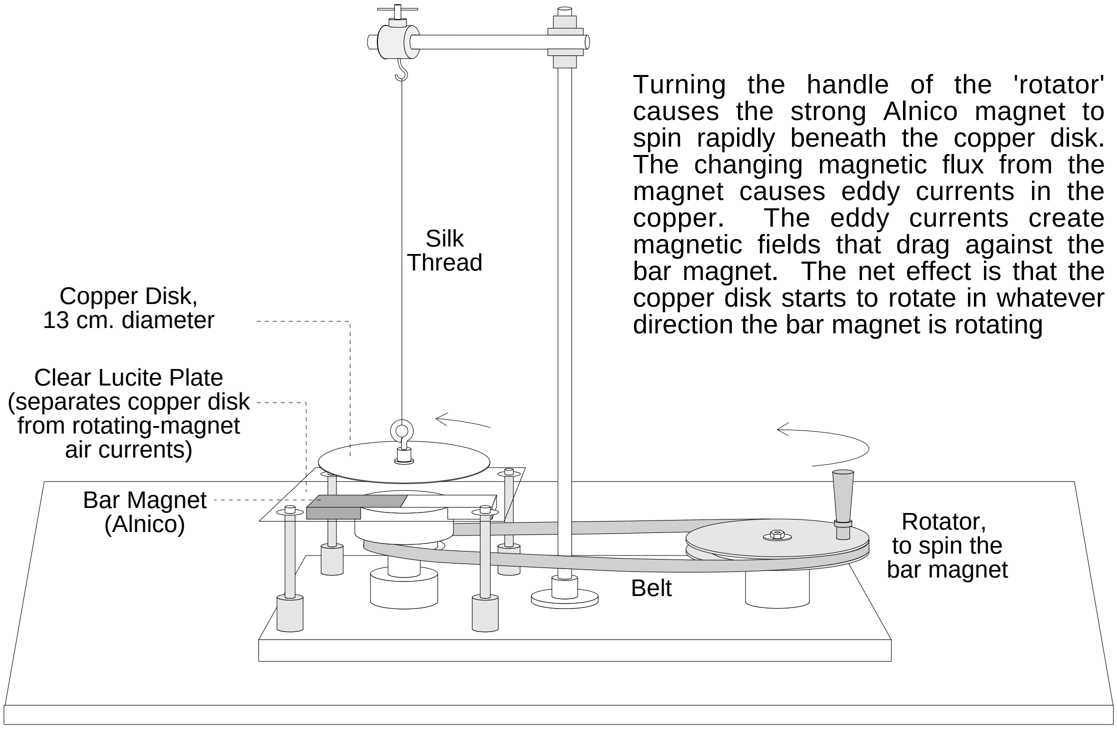


Note: A projection ammeter and voltmeter can be added to the circuit, if desired.

FARADAY'S LAW.

D+15+14

Eddy currents: Copper disk rotates over a spinning bar magnet.



Turning the handle of the 'rotator' causes the strong Alnico magnet to spin rapidly beneath the copper disk. The changing magnetic flux from the magnet causes eddy currents in the copper. The eddy currents create magnetic fields that drag against the bar magnet. The net effect is that the copper disk starts to rotate in whatever direction the bar magnet is rotating

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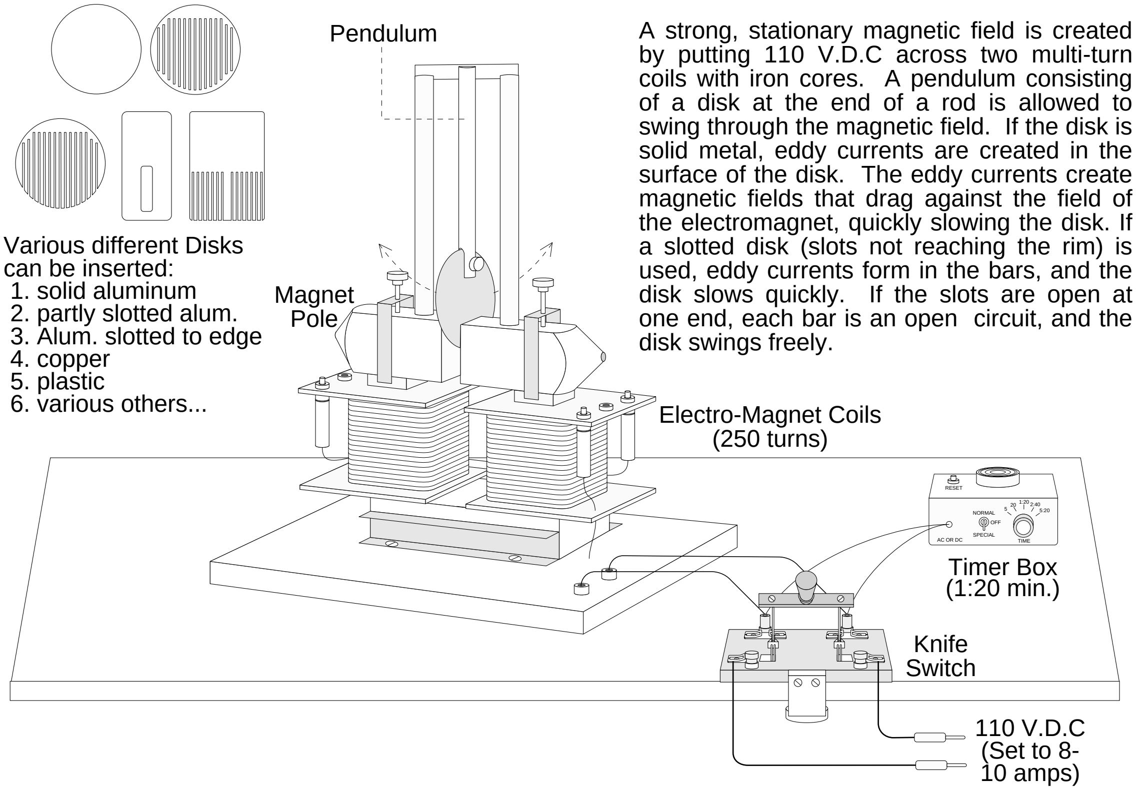
FARADAY'S LAW.

D+15+16

Damped pendulum: Swinging metal disks damped in magnetic field.



Various different Disks can be inserted:

1. solid aluminum
2. partly slotted alum.
3. Alum. slotted to edge
4. copper
5. plastic
6. various others...

A strong, stationary magnetic field is created by putting 110 V.D.C across two multi-turn coils with iron cores. A pendulum consisting of a disk at the end of a rod is allowed to swing through the magnetic field. If the disk is solid metal, eddy currents are created in the surface of the disk. The eddy currents create magnetic fields that drag against the field of the electromagnet, quickly slowing the disk. If a slotted disk (slots not reaching the rim) is used, eddy currents form in the bars, and the disk slows quickly. If the slots are open at one end, each bar is an open circuit, and the disk swings freely.

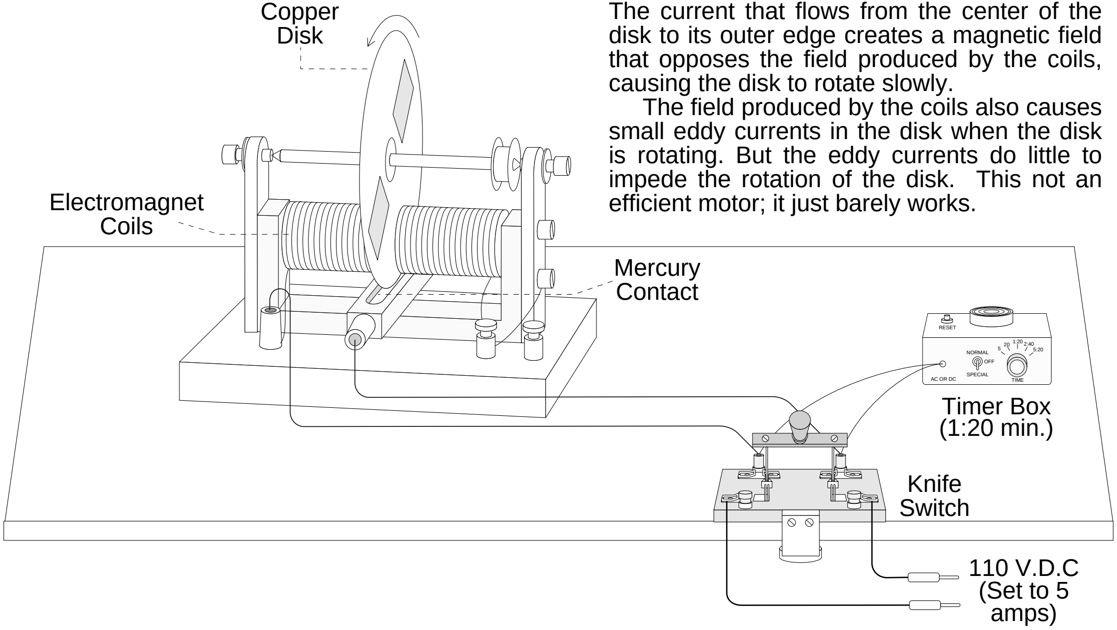
FARADAY'S LAW.

D+15+18

Faraday's Disk: Copper disk in Hg rotates in magnetic field.

A strong, stationary magnetic field is created by putting 110 V.D.C across two multi-turn coils with iron cores. Mounted between the electromagnets is a copper disk, free to rotate. 110 VDC is also put across the disk, whose bottom edge sits in a pool of mercury. The current that flows from the center of the disk to its outer edge creates a magnetic field that opposes the field produced by the coils, causing the disk to rotate slowly.

The field produced by the coils also causes small eddy currents in the disk when the disk is rotating. But the eddy currents do little to impede the rotation of the disk. This not an efficient motor; it just barely works.

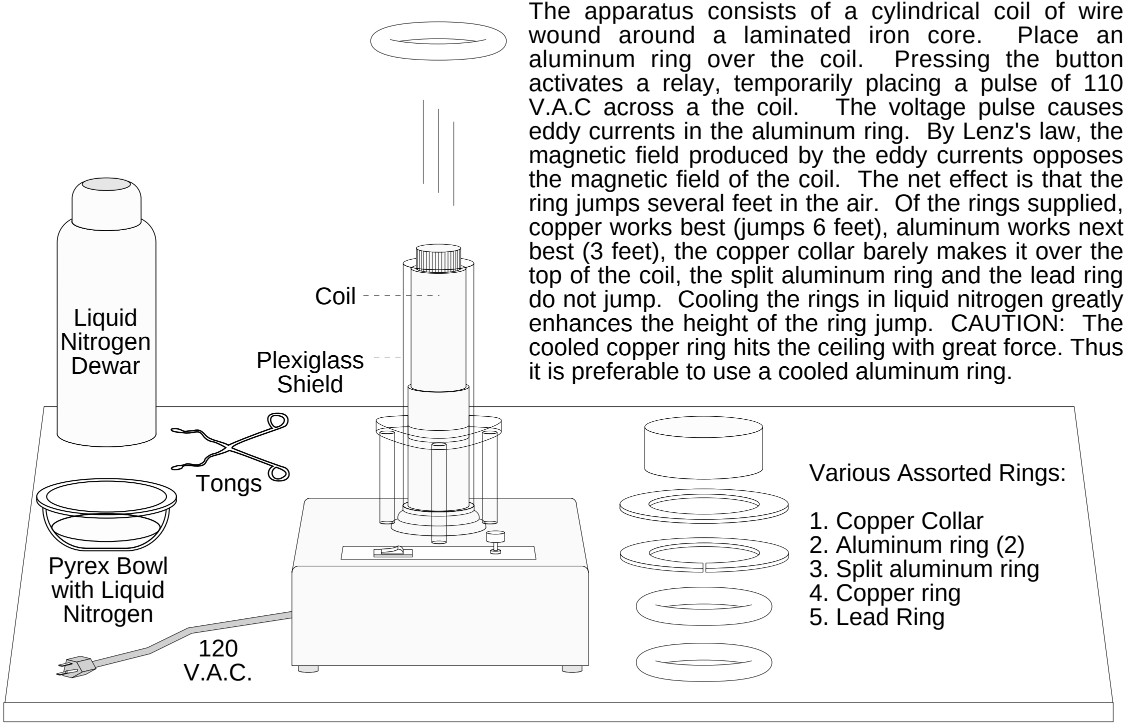


FARADAY'S LAW.

D+15+20

Jumping Rings: High current AC coil causes rings to jump.

This is the Elihu Thompson 'Jumping Ring' experiment. The apparatus consists of a cylindrical coil of wire wound around a laminated iron core. Place an aluminum ring over the coil. Pressing the button activates a relay, temporarily placing a pulse of 110 V.A.C across a the coil. The voltage pulse causes eddy currents in the aluminum ring. By Lenz's law, the magnetic field produced by the eddy currents opposes the magnetic field of the coil. The net effect is that the ring jumps several feet in the air. Of the rings supplied, copper works best (jumps 6 feet), aluminum works next best (3 feet), the copper collar barely makes it over the top of the coil, the split aluminum ring and the lead ring do not jump. Cooling the rings in liquid nitrogen greatly enhances the height of the ring jump. CAUTION: The cooled copper ring hits the ceiling with great force. Thus it is preferable to use a cooled aluminum ring.



Various Assorted Rings:

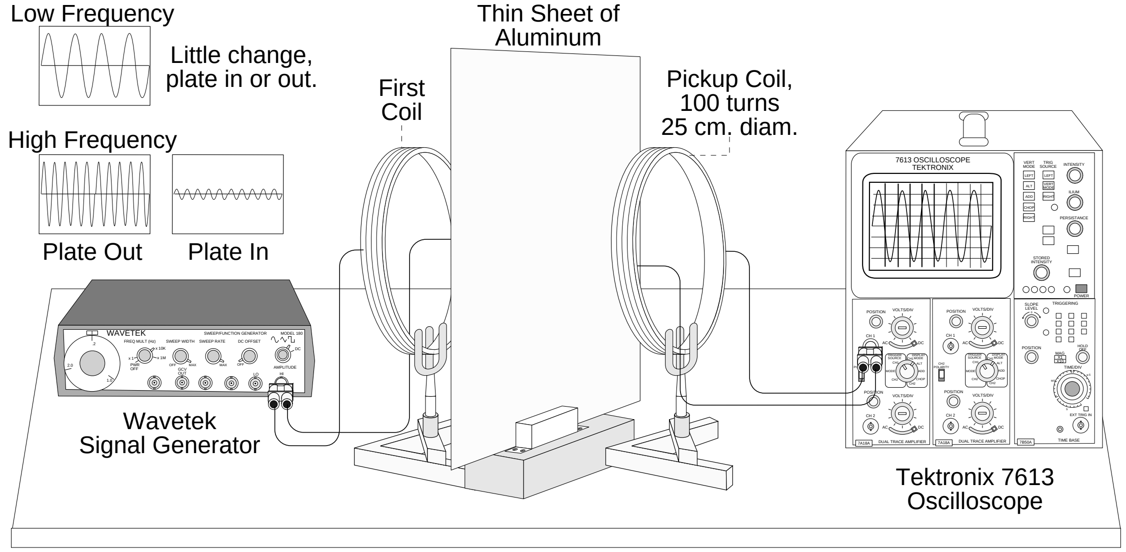
1. Copper Collar
2. Aluminum ring (2)
3. Split aluminum ring
4. Copper ring
5. Lead Ring

FARADAY'S LAW.

D+15+22

Skin effect: Metal sheet shielding varies with frequency.

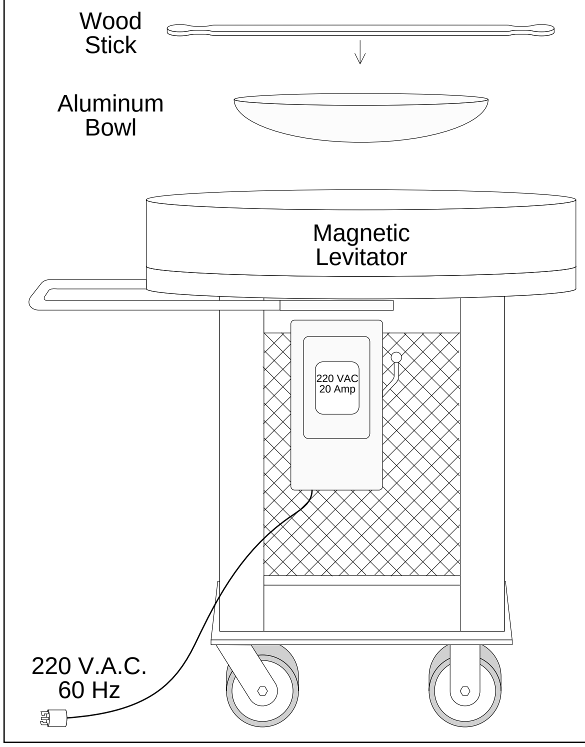
This apparatus demonstrates the 'Skin effect'. The signal generator supplies a sinusoidal voltage to the first coil of wire, creating an sinusoidal magnetic field. The a.c. magnetic field penetrates the aluminum sheet. In the aluminum, if the flux $\phi = A\sin \omega t$, then the induced voltage = $d\phi/dt = A\omega\cos \omega t$. Thus, as ω gets larger, the induced voltage in the aluminum gets larger; the resultant eddy currents get larger; the repelling B-field from the eddy currents gets larger which helps to cancel out the B-field from the first coil. The net effect is that the B-field in the aluminum dies away exponentially as it leaves the front surface. This 'Skin effect' is minimal at low frequencies (10 Hz), and most of the B-field gets through the back surface to be picked up by the second coil. At high frequencies (10KHz and higher) little of the B-field gets through and the aluminum acts as a shield.



FARADAY'S LAW.

D+15+24

Levitator: Aluminum dish floats four inches off platform.



This apparatus is a magnetic levitator, illustrating Lenz's law. The levitator can support an aluminum bowl about a foot in mid air in stable equilibrium.

The levitator is an electromagnet of special design. The top consists of concentric wire coils and an hexagonal array of iron cores. 220 V.A.C., at 60 Hertz, is applied to the coils, causing an intense alternating magnetic field. When the aluminum pan is placed in the field, eddy currents form in the aluminum, causing magnetic fields in the direction opposite to the levitator fields. The force on the bowl is upward, and sufficient to counteract the weight of the aluminum.

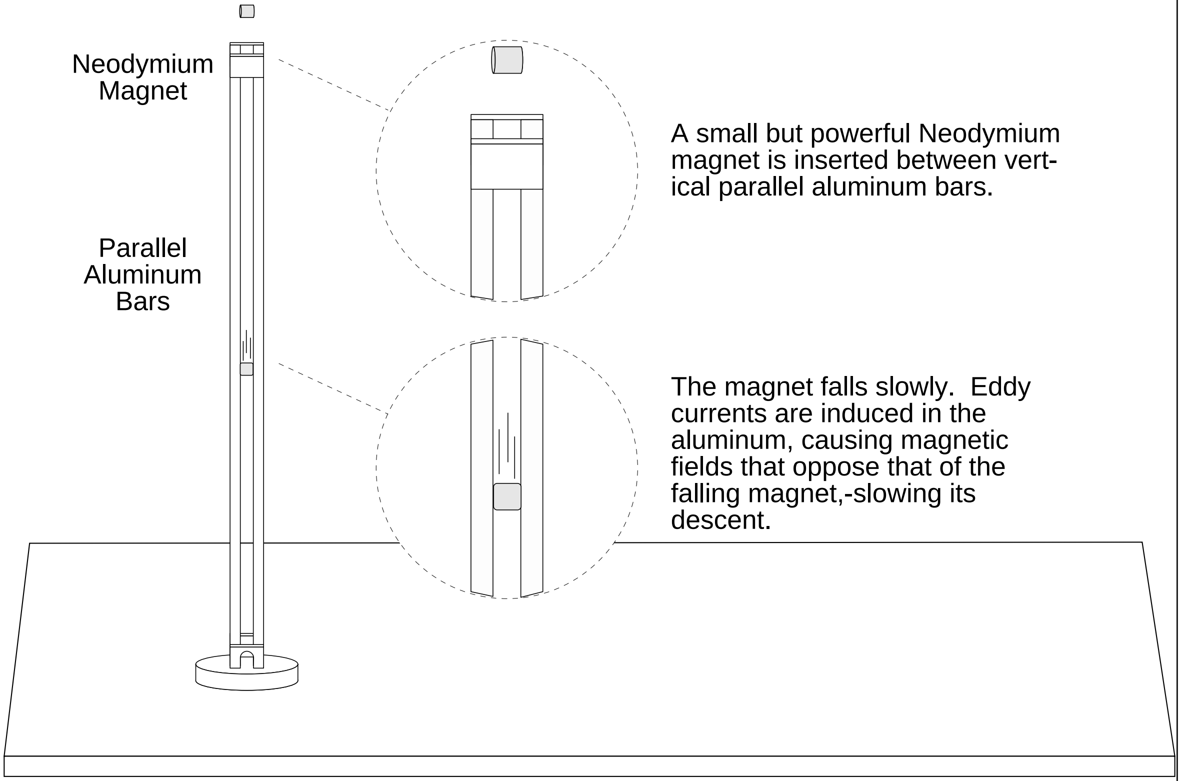
Should the bowl move to one side, the eddy currents give rise to a greater repulsive force on that side, causing the bowl to move back to center position. If the bowl tips, it experiences a force that restores it to horizontal equilibrium.

If a wood stick is used to press down on the bowl, the eddy currents increase significantly, causing the bowl to heat up dramatically. Some professors have cooked eggs in the bowl!

Because the coil windings of the levitator have a large inductive reactance, a large capacitance is inserted in the ac circuit (in the bottom part of levitator cabinet) to raise the power factor close to unity. I.E.: The current in the levitator coils is kept at a maximum, and the current supplied by the source is at a minimum.

FARADAY'S LAW. D+15+26

Magnet drops slowly between aluminum bars due to eddy current effect.



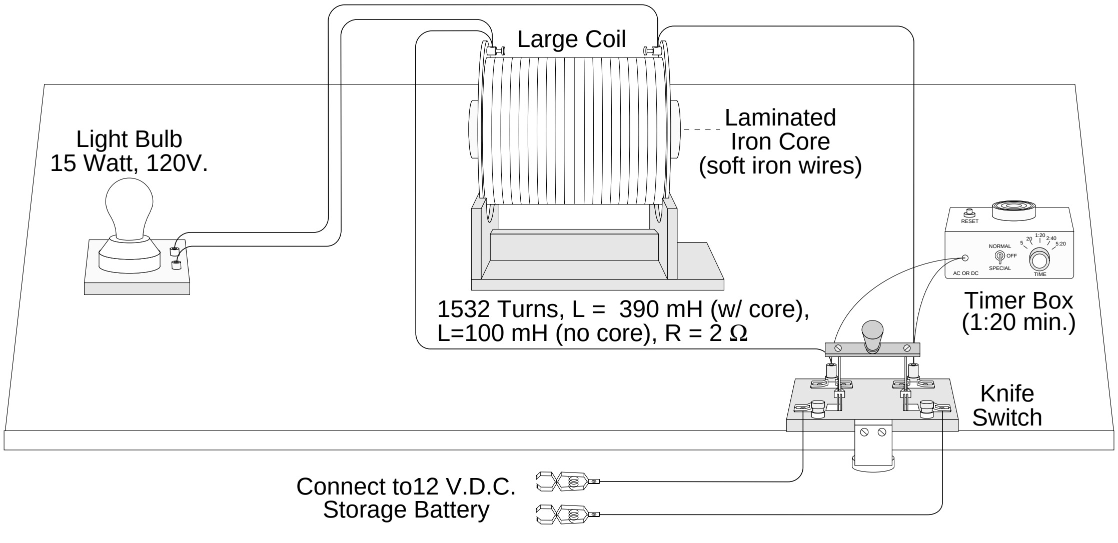
A small but powerful Neodymium magnet is inserted between vertical parallel aluminum bars.

The magnet falls slowly. Eddy currents are induced in the aluminum, causing magnetic fields that oppose that of the falling magnet,-slowing its descent.

INDUCTANCE. D+20+0

Energy stored in large coil with soft iron core flashes bulb.

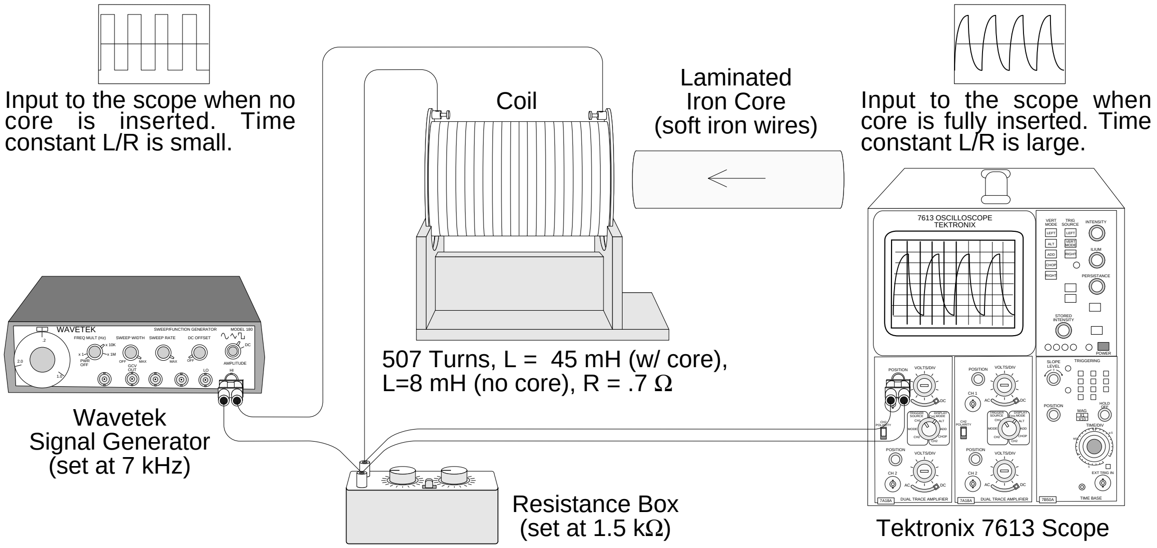
A laminated iron core is inserted into a large coil of 1532 turns. A 12 V.D.C. car battery is hooked up to the coil via a knife switch, and a 15 watt, 120 Volt bulb is attached in parallel. When the switch is closed, the bulb glows dimly. Most of the energy goes into the coil magnetic field. However, when the switch is quickly opened, the bulb flashes brightly. The energy from the collapsing magnetic field of the coil surges through the bulb, causing a brief flash.



INDUCTANCE. D+20+2

LR time constant: Square wave drives series LR on oscilloscope.

A signal generator places a 7 kHz square wave across a coil of 507 turns and a series resistor (1.5 kΩ). A laminated core is slowly inserted into the coil. When the voltage in the square wave goes suddenly positive, a current starts to flow in the inductor. This current is opposed by the induced emf in the inductor. However, as the current starts flowing, there is also a voltage drop across the resistor. Thus the voltage drop across the inductance is reduced, and there is less impedance to the current flow from the inductance. The current through the LR circuit rises exponentially until it reaches the value V/R, with a characteristic time constant L/R. When the square wave is suddenly zero, the current decays exponentially to 0, with the same time constant. When the square wave goes negative, similar arguments apply. When the core is fully inserted, L/R is large, and the scope signal is no longer a 'square' wave, but a series of scalloped rises and falls.



Input to the scope when no core is inserted. Time constant L/R is small.

Input to the scope when core is fully inserted. Time constant L/R is large.

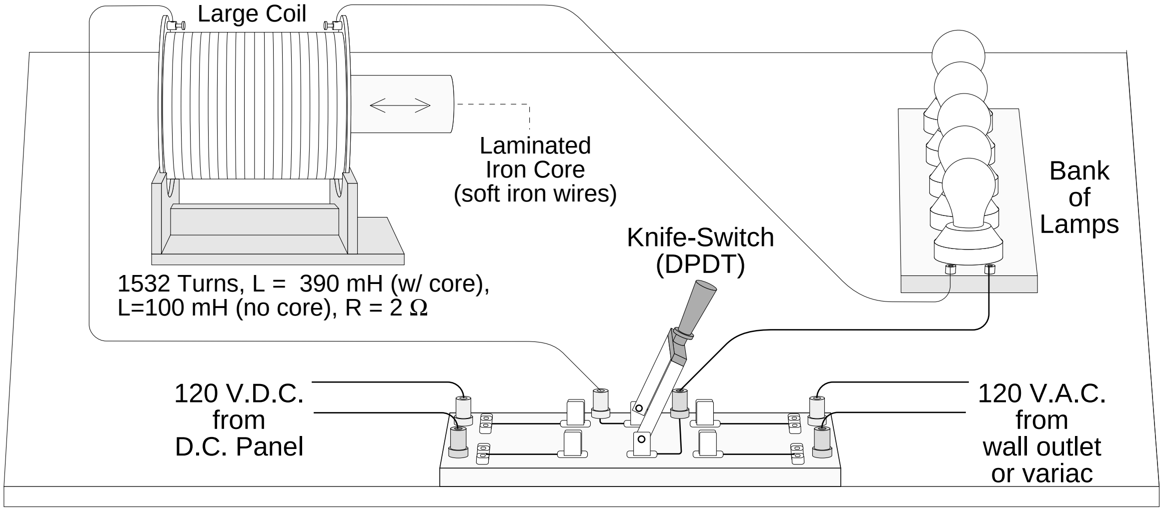
507 Turns, L = 45 mH (w/ core), L=8 mH (no core), R = .7 Ω

INDUCTANCE. D+20+4

AC dimmer: Soft iron core in coil dims lamps.

This is a series LR circuit (as was D+20+2). The lamps are the resistance R in this case. Either 120 V.D.C. or 120 V.A.C. can be applied by throwing the knife-switch, lighting the lamps. When D.C. voltage is selected, inserting the laminated iron core will cause no variation in the brightness of the lamps. However, if 60 Hz A.C. voltage is selected, inserting the core will cause the lamps to dim. Completely inserting the core will cause the lamps to completely turn off.

For the 120 V.D.C. case, the resistance of the lamps (in parallel) is about 30 Ω, and the current flowing is about 4 amps; plenty of current to light the lamps. There is no inductive impedance; no induced emf. But in the 120 V.A.C. case, there is an inductive impedance; and a rather large induced emf, especially when the core is inserted. When the core is inserted, the impedance of the inductor $X_L = 2\,\Pi\, f\, L = 2\text{x}3.14\text{x}(60\text{ Hz})\text{x}(.390\text{ H}) = 147\ \Omega$, which means the current flowing in the circuit will be at least 80% reduced, and not enough to light the lamps.



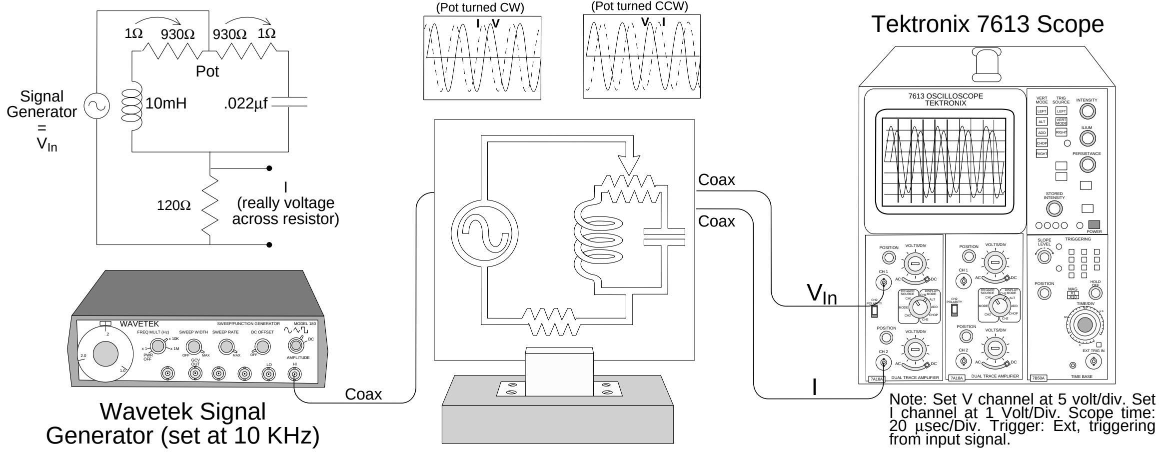
1532 Turns, L = 390 mH (w/ core), L=100 mH (no core), R = 2 Ω

LCR PHASE RELATIONSHIPS. D+25+0

Phases of V and I in series circuit as RL shifts to RC.

This circuit is designed to show how the current shifts phase with-respect-to voltage, in an RC or RL circuit. A voltage waveform is displayed on the scope, along with a 'current' waveform. Turning a potentiometer clockwise (cw) or counterclockwise (ccw) on the back of the board, shifts the current waveform left or right with-respect-to (wrt) the voltage waveform.

However, you will notice that the circuit shown is actually an LCR 'tank' circuit, with the R being a variable potentiometer. The values of L and C are chosen so that the resonant frequency is at 10.7 KHz, and the impedance of L and C at this frequency are both the same (674 Ω). At resonance, when the pot is set at midrange, there is no current phase shift wrt voltage. However, as you turn the pot cw, more resistance moves into the inductor branch of the circuit, reducing the amount of current in the inductor branch; increasing the amount of current in the capacitor branch of the circuit. When the pot is fully cw, you have virtually an RC circuit, with the current leading the voltage about 80 degrees. By the same reasoning, moving the pot ccw causes the circuit to shift toward being an RL circuit. When the pot is fully ccw, you have virtually an RL circuit with the current lagging behind the voltage by about 80 degrees.

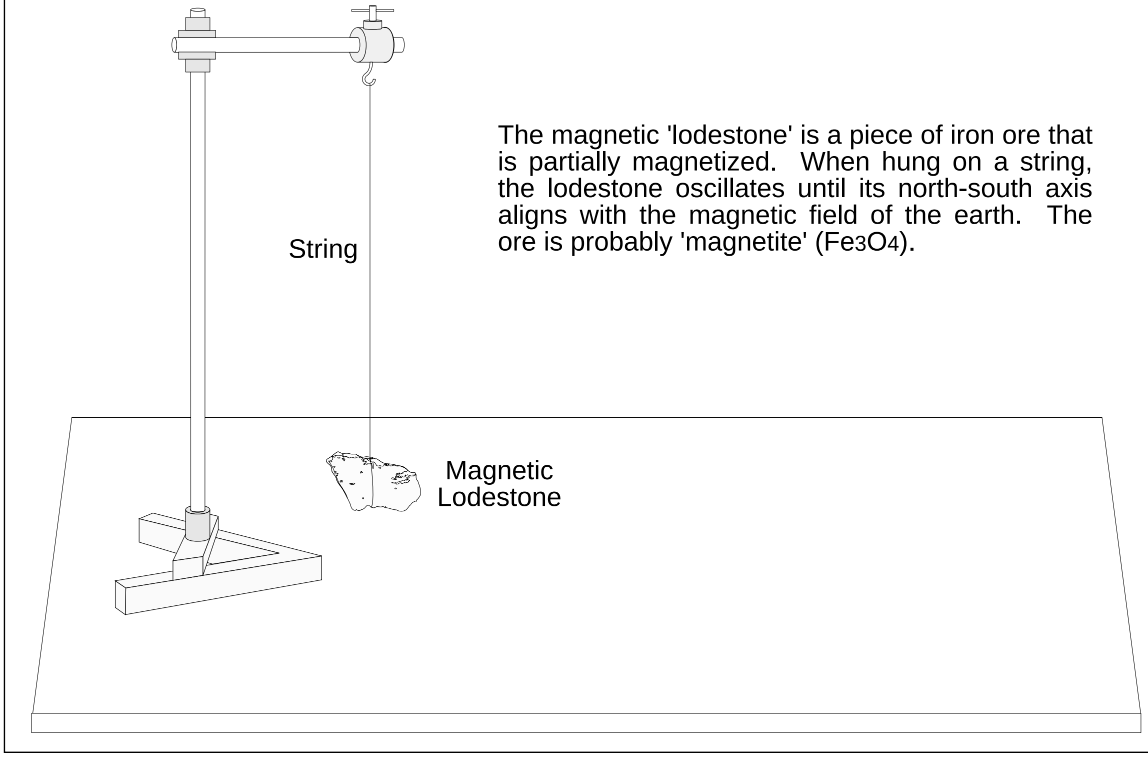


Note: Set V channel at 5 volt/div. Set I channel at 1 Volt/Div. Scope time: 20 µsec/Div. Trigger: Ext, triggering from input signal.

MAGNETIC FIELDS. D+30+0

Suspended magnetic lodestone on string.

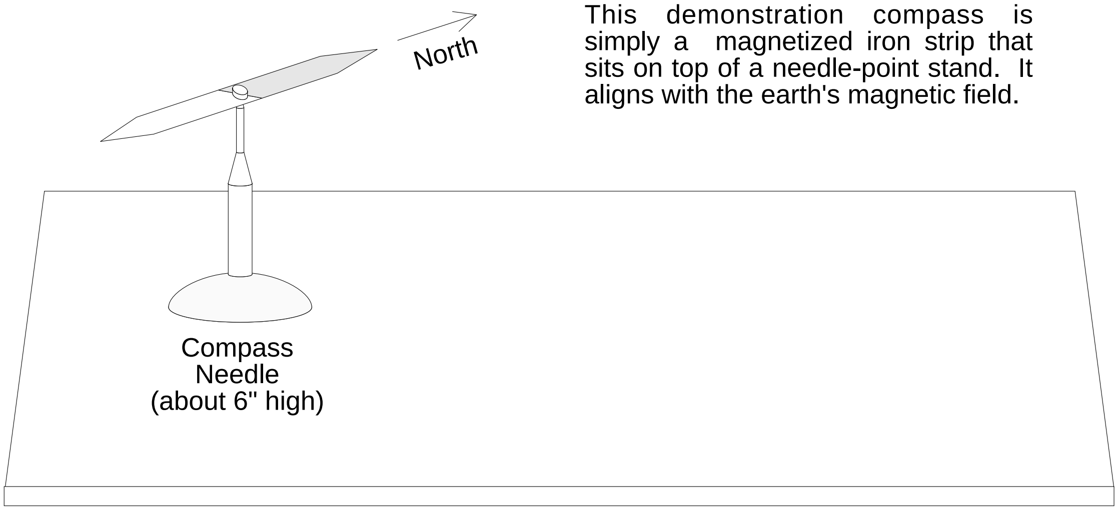
The magnetic 'lodestone' is a piece of iron ore that is partially magnetized. When hung on a string, the lodestone oscillates until its north-south axis aligns with the magnetic field of the earth. The ore is probably 'magnetite' (Fe_3O_4).



MAGNETIC FIELDS. D+30+1

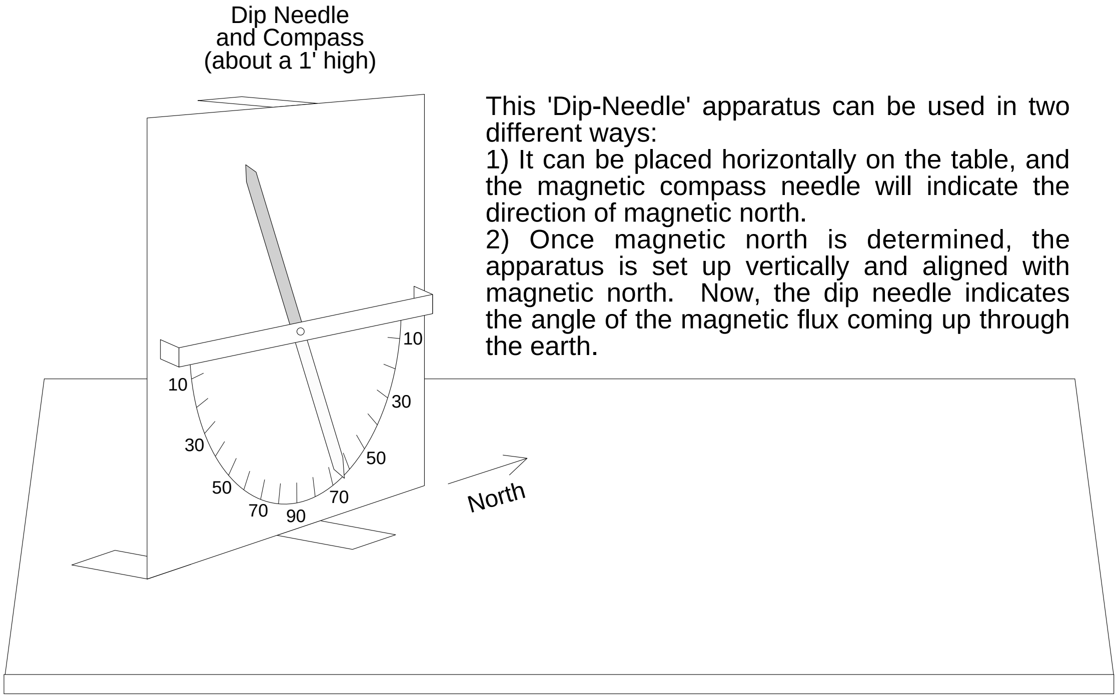
Large compass needle on stand.

This demonstration compass is simply a magnetized iron strip that sits on top of a needle-point stand. It aligns with the earth's magnetic field.



MAGNETIC FIELDS. D+30+2

Dip needle compass.

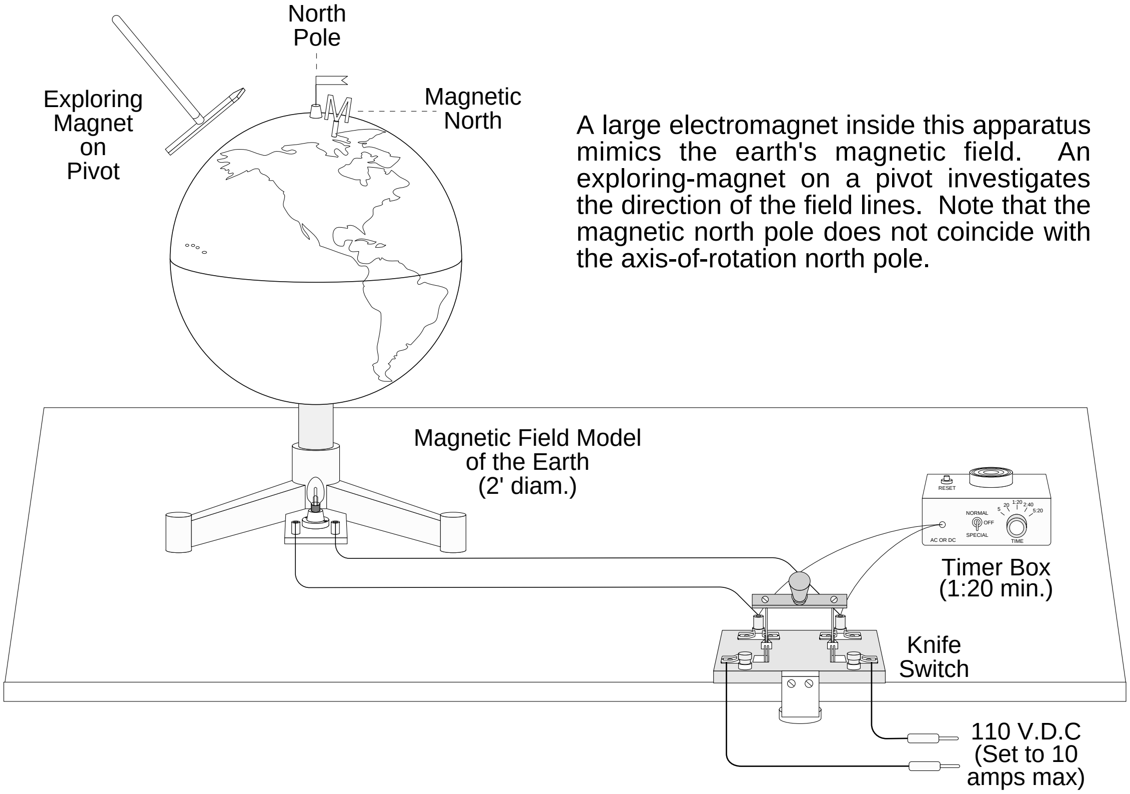


This 'Dip-Needle' apparatus can be used in two different ways:
1) It can be placed horizontally on the table, and the magnetic compass needle will indicate the direction of magnetic north.
2) Once magnetic north is determined, the apparatus is set up vertically and aligned with magnetic north. Now, the dip needle indicates the angle of the magnetic flux coming up through the earth.

MAGNETIC FIELDS.

D+30+4

Earth model with internal magnet and pivoting probe magnet.

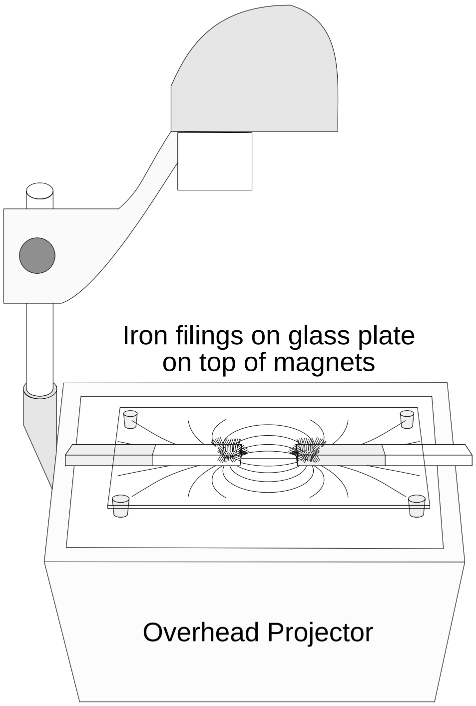


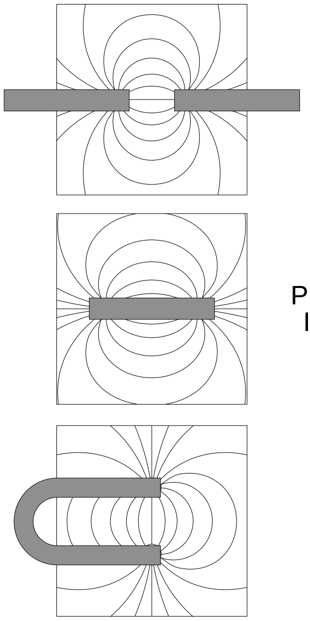
A large electromagnet inside this apparatus mimics the earth's magnetic field. An exploring-magnet on a pivot investigates the direction of the field lines. Note that the magnetic north pole does not coincide with the axis-of-rotation north pole.

MAGNETIC FIELDS.

D+30+6

Iron filings and permanent magnets to show field on an OHP.

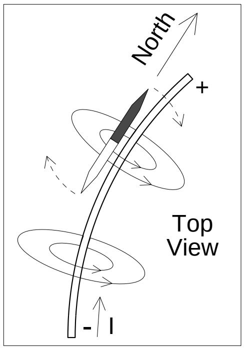




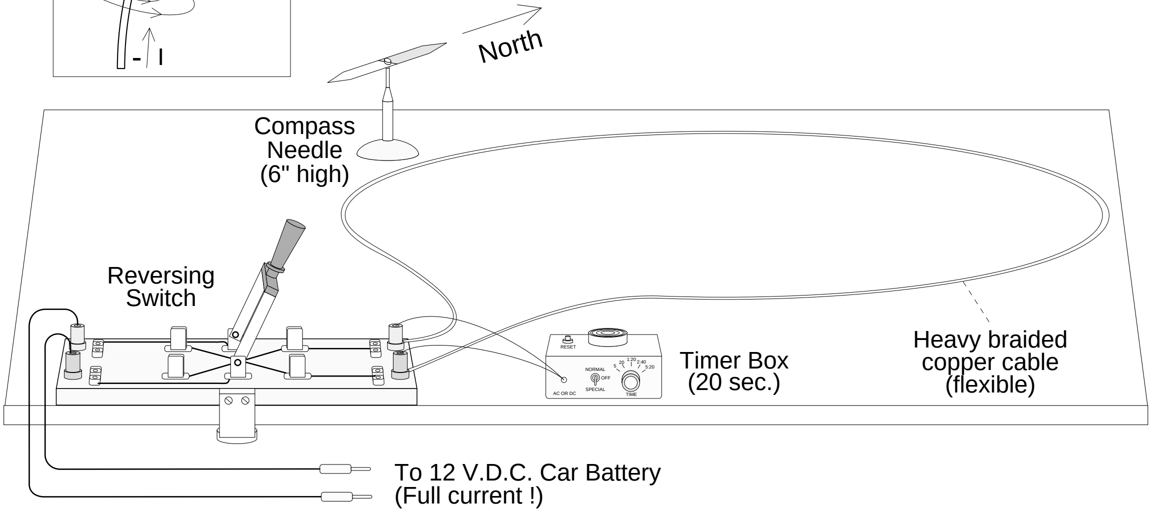
Various different magnets (bar, horseshoe, 2 bars etc.) are placed under a glass plate, on an overhead projector. Iron filings are sprinkled on top of the plate. The filings line up with the magnetic field lines , and are clearly visible when projected onto a screen.

MAGNETIC FIELDS. D+30+8

Oersted's Expt.: Compass needle shows field around a high current wire.



A large current (amps) passes through a braided copper cable, creating a circular magnetic field with the cable as its axis (determined by the right-hand rule). The compass needle tries to align itself so it is tangent to a circle drawn around the wire. Viewed from above, it appears that the needle swings so as to be perpendicular to the wire. The reversing switch can be thrown so that the current goes in the opposite direction, and the needle will swing in the opposite direction.

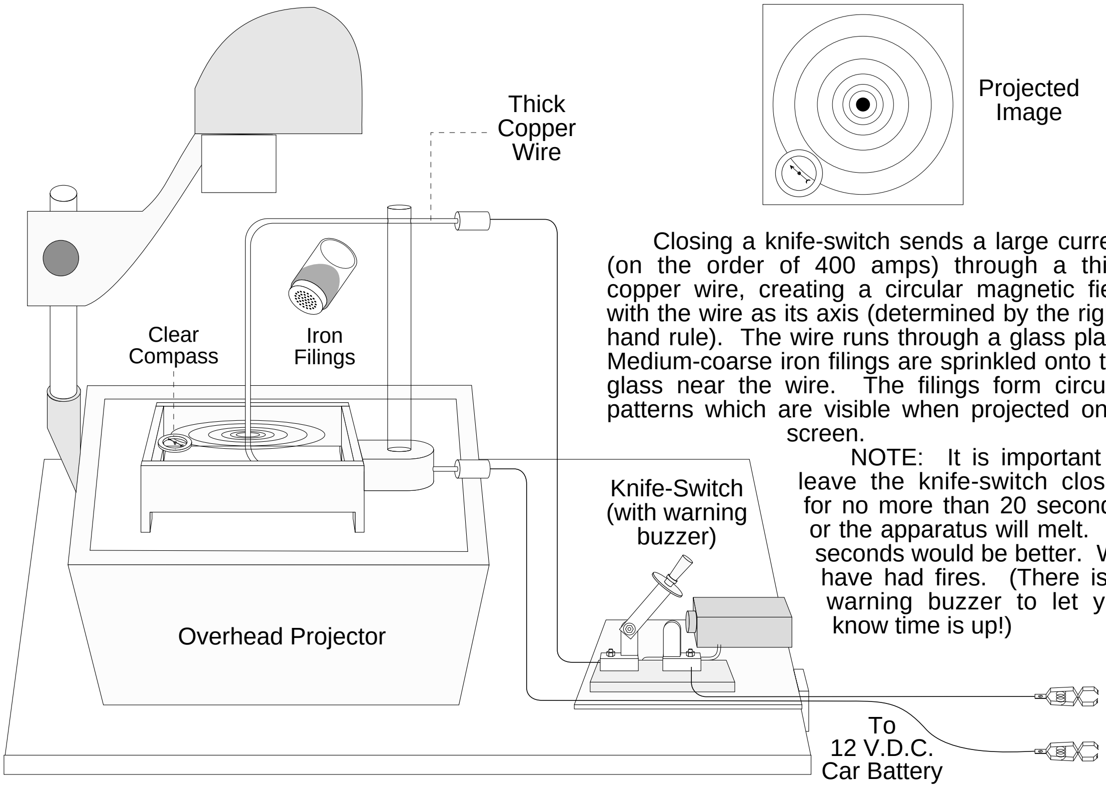


MAGNETIC FIELDS. D+30+10

Iron filings around a high current vertical wire on OHP to show field.

Closing a knife-switch sends a large current (on the order of 400 amps) through a thick copper wire, creating a circular magnetic field with the wire as its axis (determined by the right-hand rule). The wire runs through a glass plate. Medium-coarse iron filings are sprinkled onto the glass near the wire. The filings form circular patterns which are visible when projected on a screen.

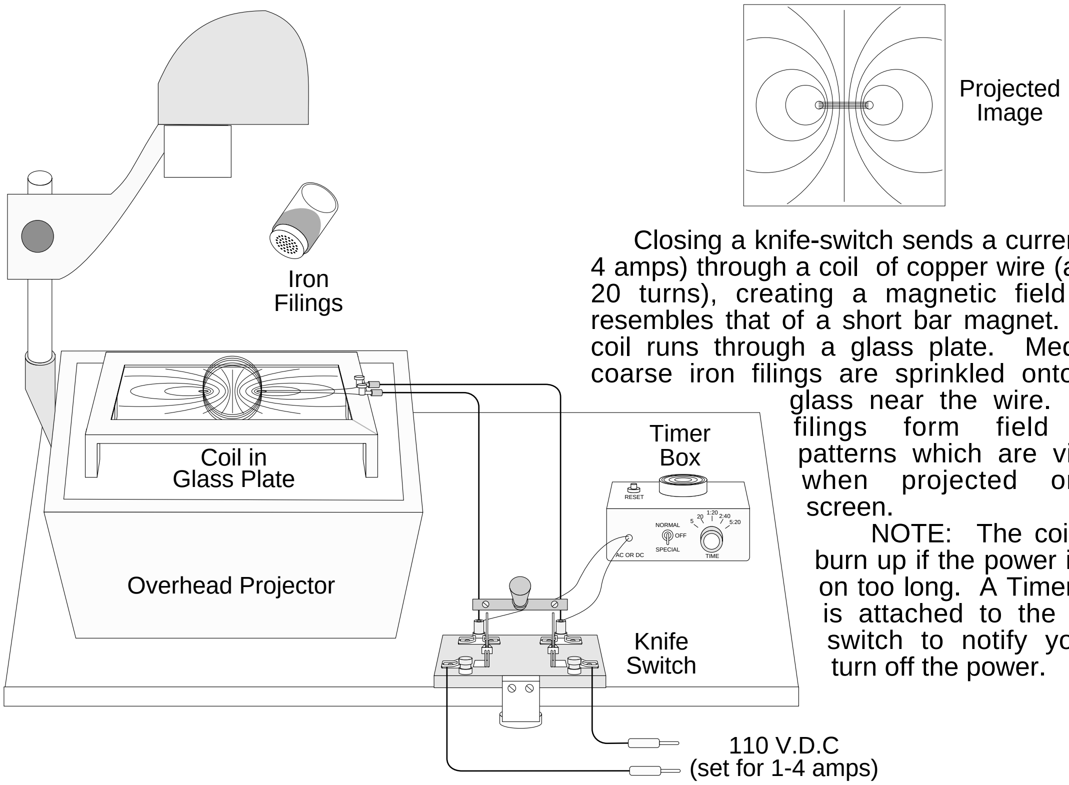
NOTE: It is important to leave the knife-switch closed for no more than 20 seconds, or the apparatus will melt. 10 seconds would be better. We have had fires. (There is a warning buzzer to let you know time is up!)



MAGNETIC FIELDS.

D+30+12

Iron filings around a current carrying coil on OHP to show field.



Closing a knife-switch sends a current (1-4 amps) through a coil of copper wire (about 20 turns), creating a magnetic field that resembles that of a short bar magnet. The coil runs through a glass plate. Medium-coarse iron filings are sprinkled onto the glass near the wire. The filings form field line patterns which are visible when projected on a screen.

NOTE: The coil can burn up if the power is left on too long. A Timer Box is attached to the knife switch to notify you to turn off the power.

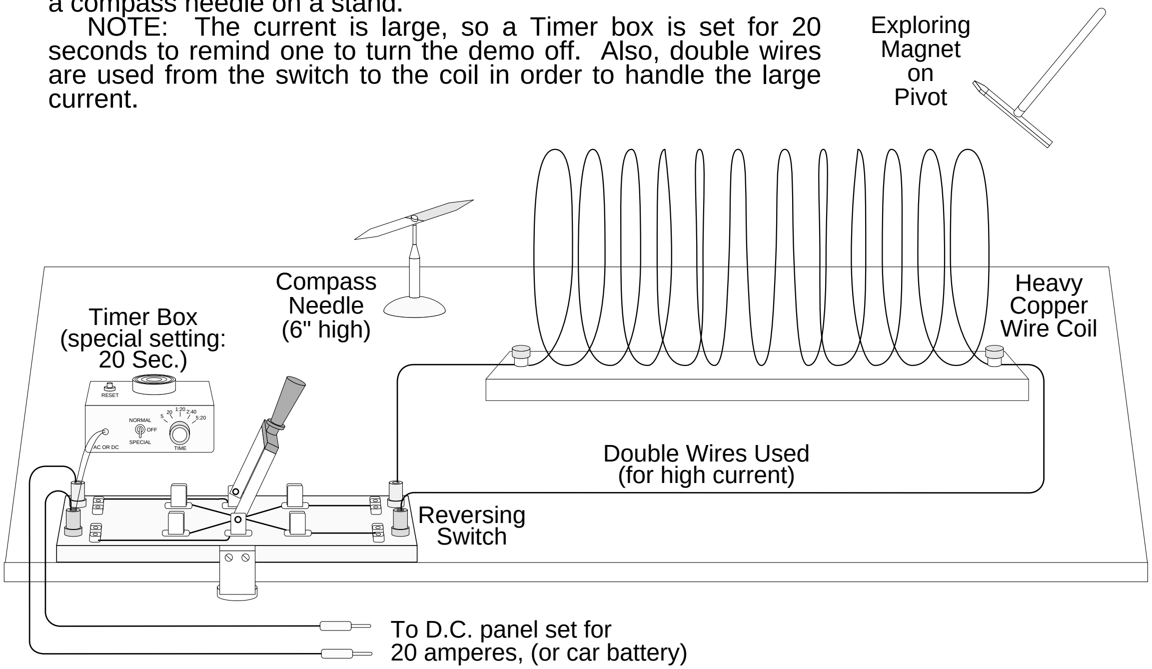
MAGNETIC FIELDS.

D+30+14

Magnetic field around a solenoid with pivoting probe magnet.

A large D.C. current (about 20 Amps), is sent through a simple solenoid coil made of heavy copper wire. The magnetic field produced is explored by a hand-held 'exploring magnet', or with a compass needle on a stand.

NOTE: The current is large, so a Timer box is set for 20 seconds to remind one to turn the demo off. Also, double wires are used from the switch to the coil in order to handle the large current.

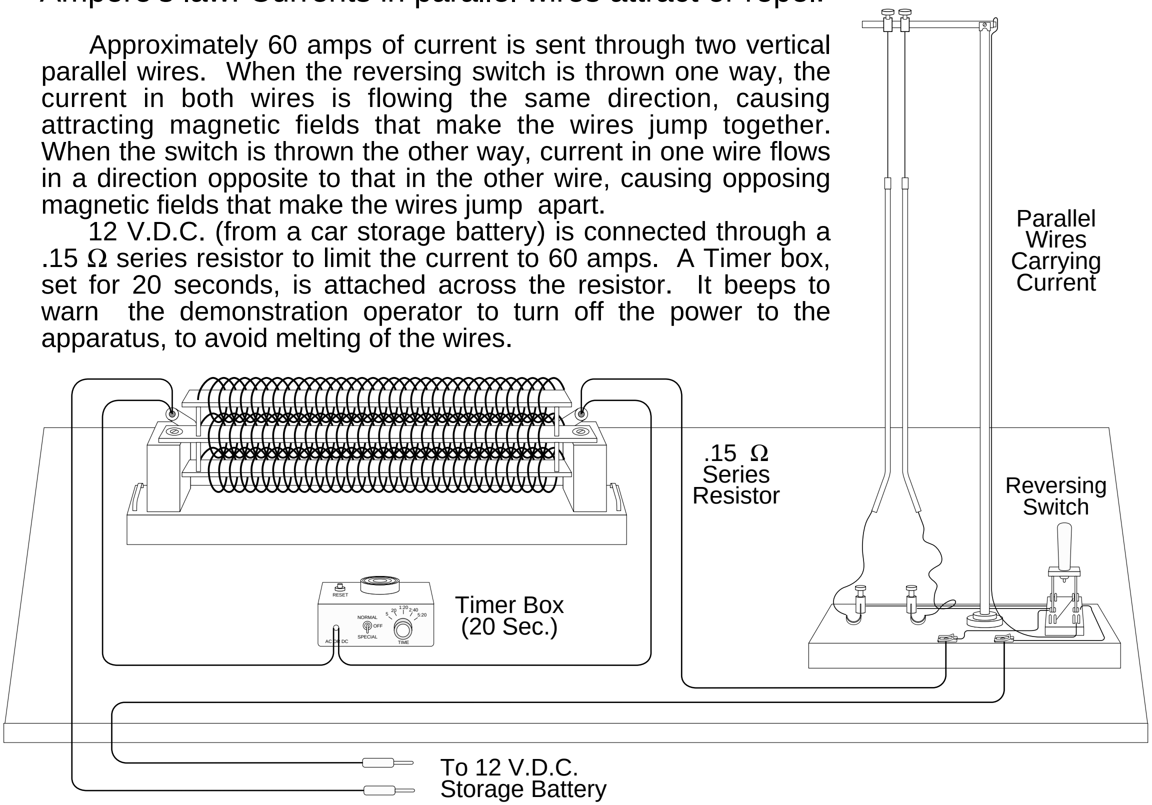


MAGNETIC FIELDS. D+30+16

Ampere's law: Currents in parallel wires attract or repel.

Approximately 60 amps of current is sent through two vertical parallel wires. When the reversing switch is thrown one way, the current in both wires is flowing the same direction, causing attracting magnetic fields that make the wires jump together. When the switch is thrown the other way, current in one wire flows in a direction opposite to that in the other wire, causing opposing magnetic fields that make the wires jump apart.

12 V.D.C. (from a car storage battery) is connected through a .15 Ω series resistor to limit the current to 60 amps. A Timer box, set for 20 seconds, is attached across the resistor. It beeps to warn the demonstration operator to turn off the power to the apparatus, to avoid melting of the wires.

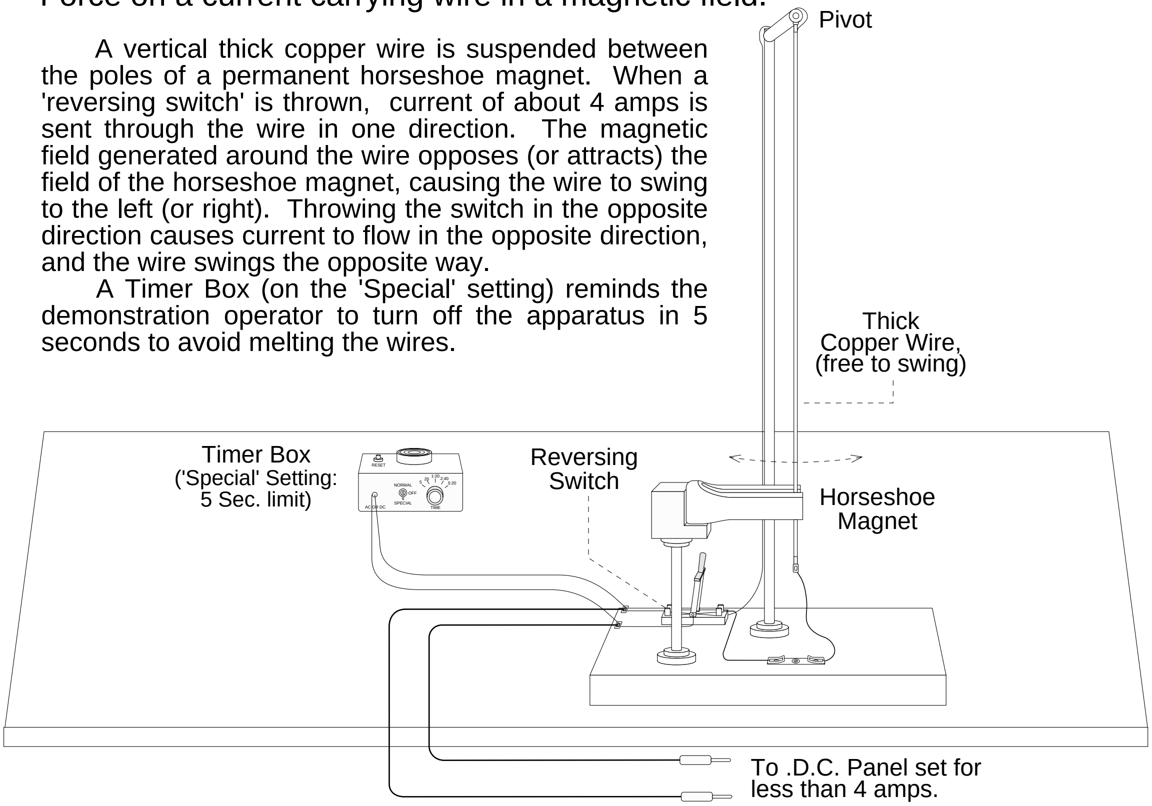


MAGNETIC FIELDS. D+30+18

Force on a current carrying wire in a magnetic field.

A vertical thick copper wire is suspended between the poles of a permanent horseshoe magnet. When a 'reversing switch' is thrown, current of about 4 amps is sent through the wire in one direction. The magnetic field generated around the wire opposes (or attracts) the field of the horseshoe magnet, causing the wire to swing to the left (or right). Throwing the switch in the opposite direction causes current to flow in the opposite direction, and the wire swings the opposite way.

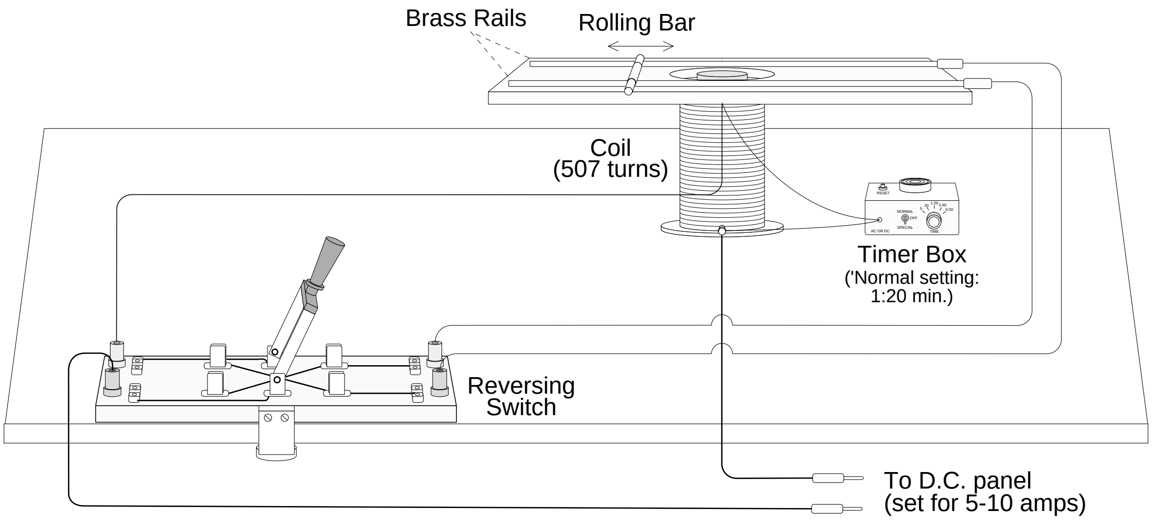
A Timer Box (on the 'Special' setting) reminds the demonstration operator to turn off the apparatus in 5 seconds to avoid melting the wires.



MAGNETIC FIELDS.

D+30+20

Elementary motor: Bar on rails over solenoid with core.



This is a simple motor. Throwing the 'reversing switch' one way sends about five amps of current (D.C.) through a large coil of wire, with a soft iron core inserted within. At the same time, current flows through two parallel brass rails and across a moveable brass bar. The field of the coil (enhanced by the core) either attracts or repels the magnetic field generated by the current flowing through the moveable bar. The bar rolls left or right. Throwing the switch in the opposite direction causes the bar to roll in the opposite direction. (The two rails and bar must be polished to insure good conduction.)

The Timer box reminds the demonstration operator to turn off the apparatus in about a minute to avoid damage to the coil.

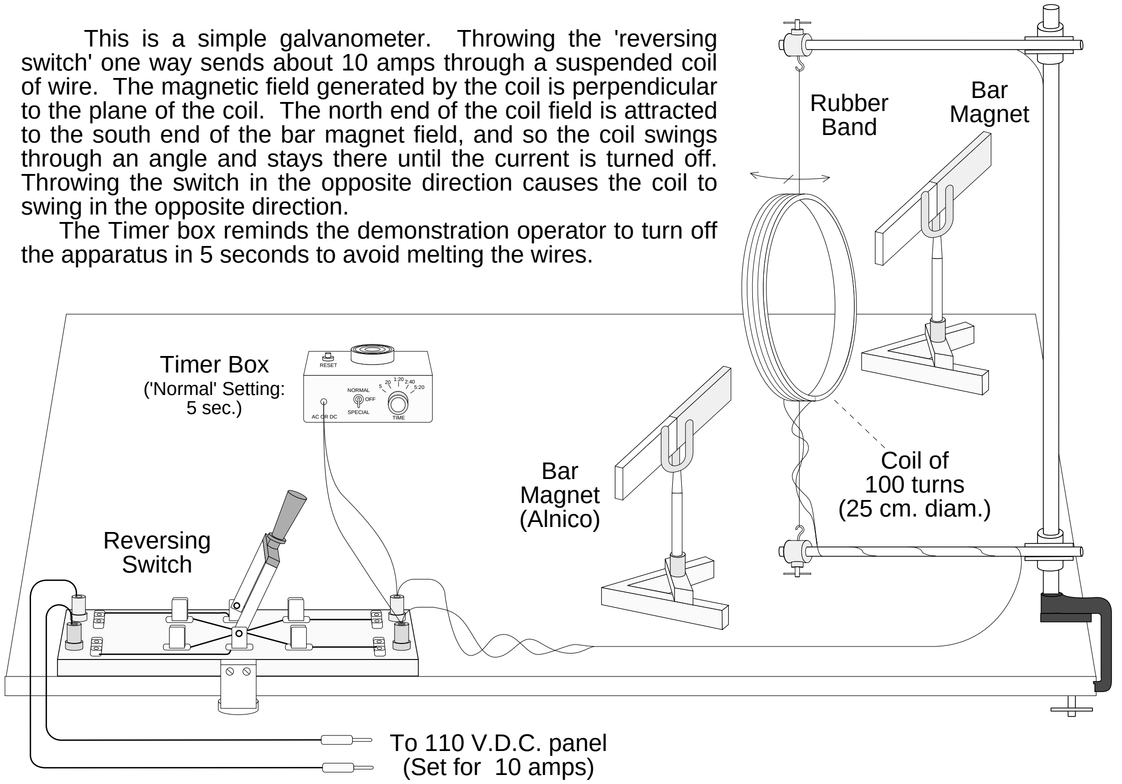
MAGNETIC FIELDS.

D+30+22

Torque on coil suspended between two magnets.

This is a simple galvanometer. Throwing the 'reversing switch' one way sends about 10 amps through a suspended coil of wire. The magnetic field generated by the coil is perpendicular to the plane of the coil. The north end of the coil field is attracted to the south end of the bar magnet field, and so the coil swings through an angle and stays there until the current is turned off. Throwing the switch in the opposite direction causes the coil to swing in the opposite direction.

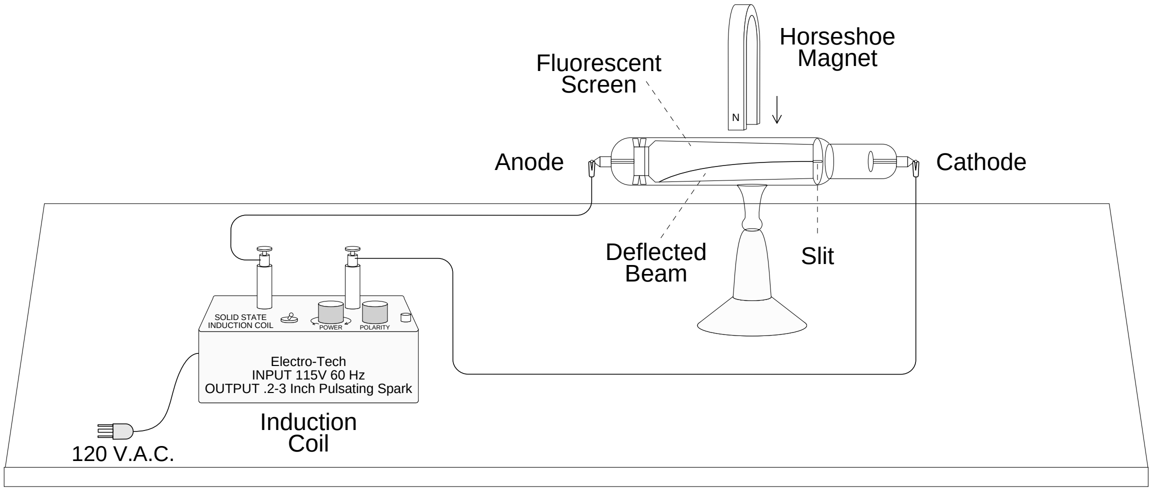
The Timer box reminds the demonstration operator to turn off the apparatus in 5 seconds to avoid melting the wires.



MAGNETIC FIELDS.

D+30+24

Vacuum tube with screen shows cathode rays bent with a magnet.

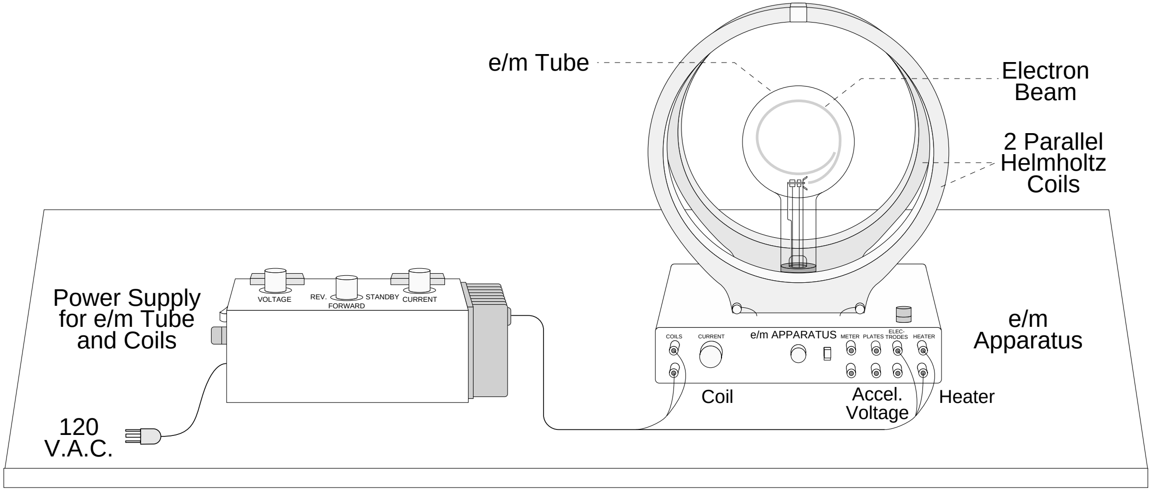


An evacuated tube has an anode at one end, a cathode at the other, and a fluorescent screen in between. When a high voltage (about 40 kV pulsating D.C.) is placed across the tube, a beam of electrons is emitted from the cathode, passes through a slit, then travels in a straight line to the anode. When a horseshoe magnet is lowered down over the tube, the beam of electrons is deflected. (By the 'right-hand screw rule', the direction of the deflection is VxB. So, the deflection of the beam is down, if the North pole of the magnet is coming out of the page...) The beam of electrons impinges on the fluorescent screen, making the path of the beam visible.

MAGNETIC FIELDS.

D+30+26

e/m Tube: Circular bending of an electron beam in a magnetic field.



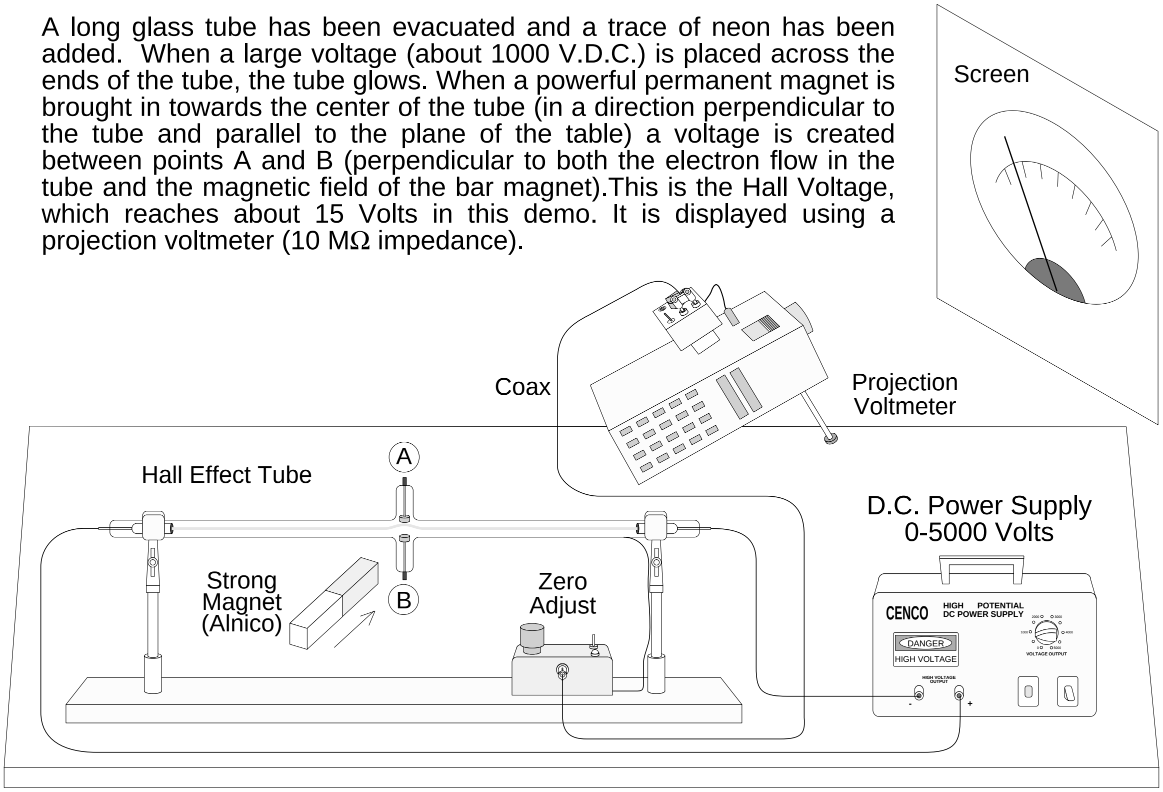
This apparatus is designed to measure e/m, the charge to mass ratio of the electron; similar to the method used by J.J. Thompson in 1897. A glass bulb is evacuated, except for a trace amount of helium. A beam of electrons is generated by a heater filament, then accelerated through a known potential V; so the velocity is known. When a current I flows in a pair of parallel Helmholtz coils, one on either side of the tube, a uniform magnetic field B is produced at right angles to the electron beam. This magnetic field deflects the beam in a circular path with radius r, which can be measured by a mirrored cm. scale. The beam is visible because the electrons collide with the helium atoms which are excited, then emit bluish light. The ratio $e/m = 2V/B^2r^2$.

The coils have a radius and separation of 15 cm. Each coil has 130 turns. The diameter of the glass bulb is 13 cm. V is varied from 150 to 300 V.D.C.. Heater voltage is 6.3 V(AC orDC). B is the product of I times 7.80×10^{-4} tesla/amp. I should be kept smaller than 3 amps (at 6-9 V.D.C.).

MAGNETIC FIELDS. D+30+28

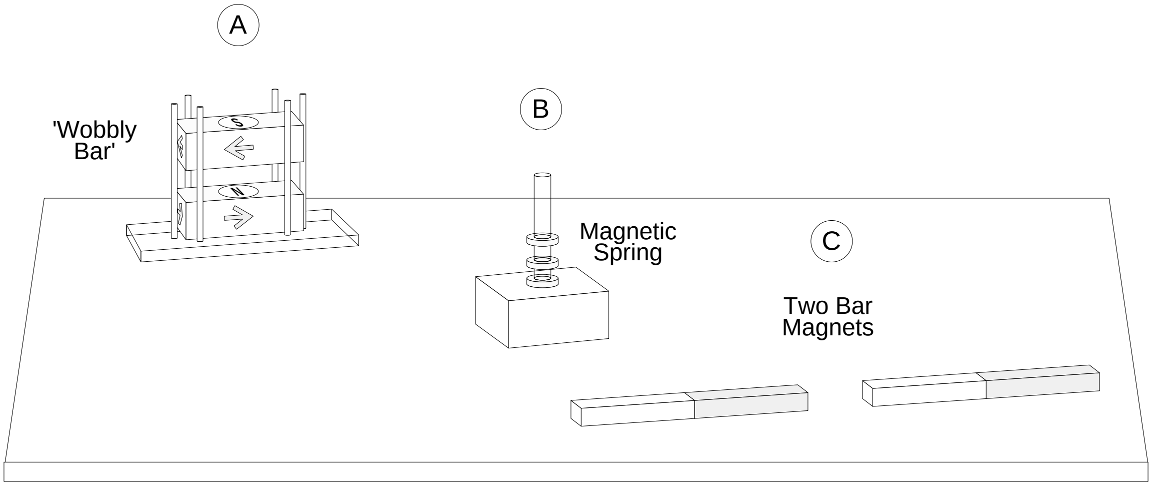
Hall Effect: Magnetic field induces a voltage in a neon plasma.

A long glass tube has been evacuated and a trace of neon has been added. When a large voltage (about 1000 V.D.C.) is placed across the ends of the tube, the tube glows. When a powerful permanent magnet is brought in towards the center of the tube (in a direction perpendicular to the tube and parallel to the plane of the table) a voltage is created between points A and B (perpendicular to both the electron flow in the tube and the magnetic field of the bar magnet).This is the Hall Voltage, which reaches about 15 Volts in this demo. It is displayed using a projection voltmeter (10 MΩ impedance).



MAGNETIC PROPERTIES. D+35+0

Wobbly bar: Magnets in frame balanced by repulsive forces.



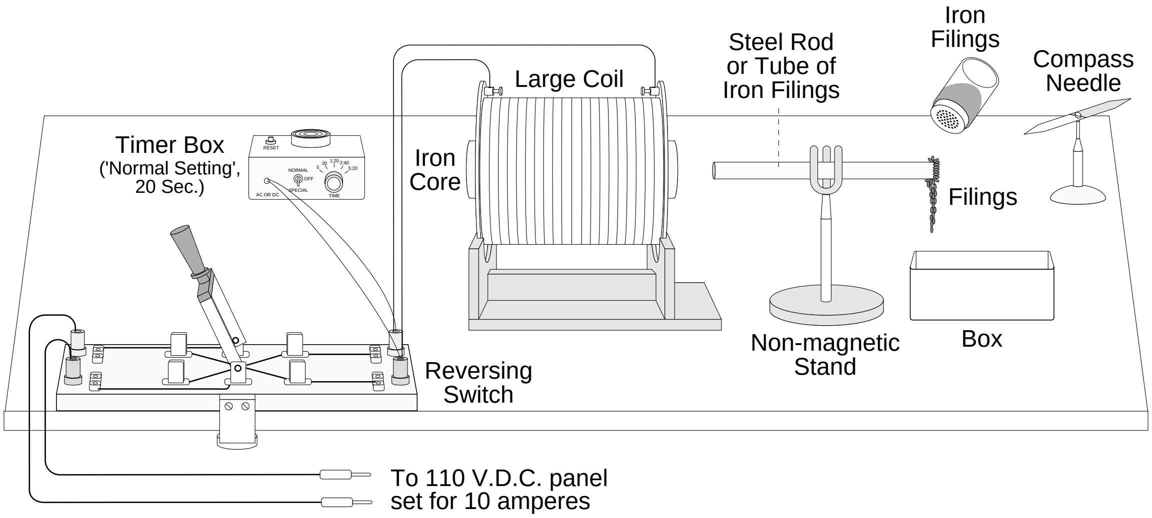
A) Two bar magnets are placed so that the top magnet 'floats' above the bottom magnet. The magnets are held in a frame so that only vertical motion is possible. The magnets are made so that the north-south pole is through the narrow 'height' rather than the length.
B) Donut-shaped magnets are suspended on a plexiglass rod so that they repel each other. The top two magnets float.
C) Two bar magnets can push or pull each other on the table top.

MAGNETIC PROPERTIES. D+35+2

Making a magnet by electromagnetic induction.

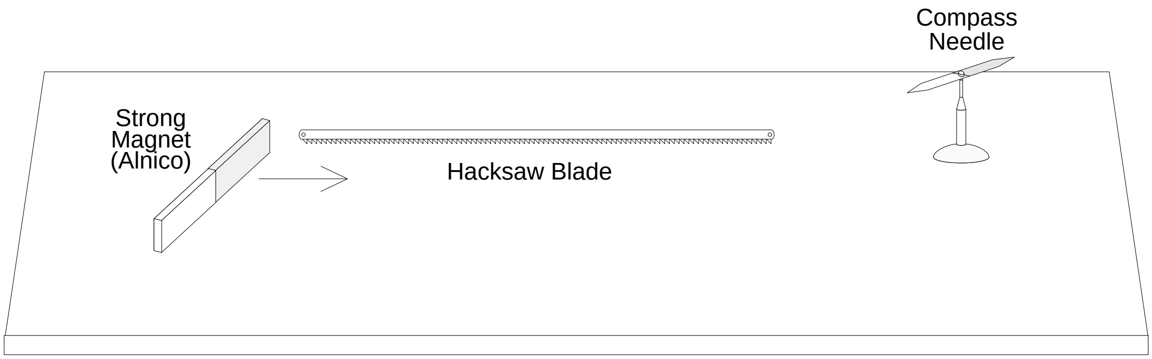
A large current (about 10 amps) is sent through a large coil fitted with an iron core, producing a strong magnetic field. A non-magnetized steel rod (or glass tube filled with iron filings) is placed near the iron core. The iron molecules in the rod (or filings in the tube) line up with the magnetic field from the coil and core, thus producing a temporary magnet capable of picking up and holding loose iron filings, nails, etc.

The Timer box reminds the demonstration operator to turn off the apparatus in 20 seconds to avoid melting the wires.



MAGNETIC PROPERTIES. D+35+4

Making small magnets by breaking up a larger magnet.

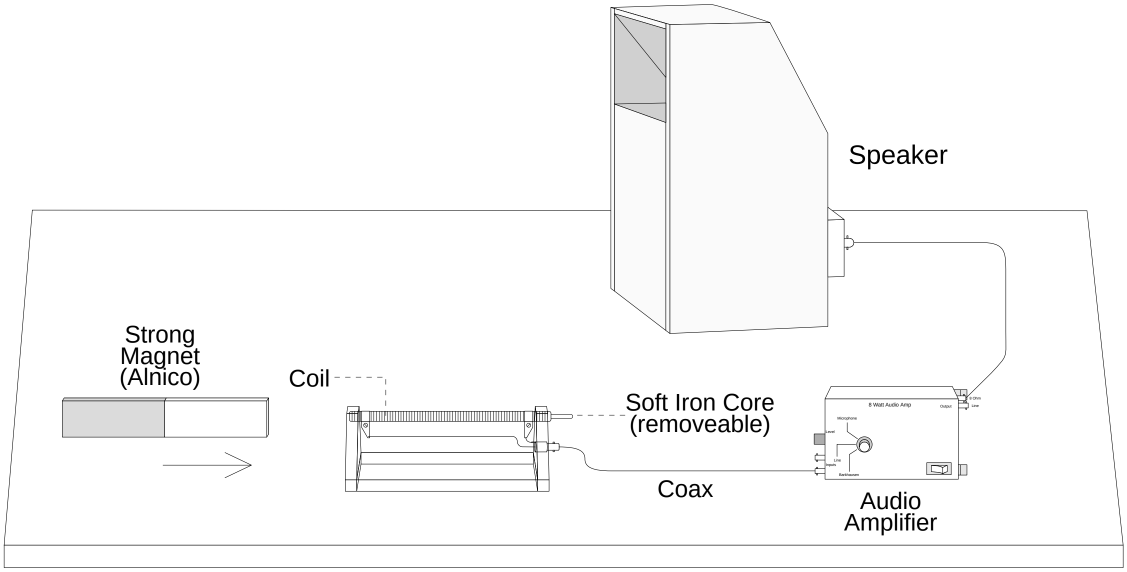


A hacksaw blade (brittle steel) can be magnetized by stroking it a number of times with a strong magnet. Stroke each time in the same direction, with the same pole (north or south) rubbing against the hacksaw surface. To see that the blade is a magnet, place one end near the compass needle and observe which end of the needle is attracted. Then place the opposite end of the blade near the needle and watch the needle swing in the opposite direction.

The blade can then be snapped by hand into smaller pieces. Each piece is also a magnet.

MAGNETIC PROPERTIES. D+35+6

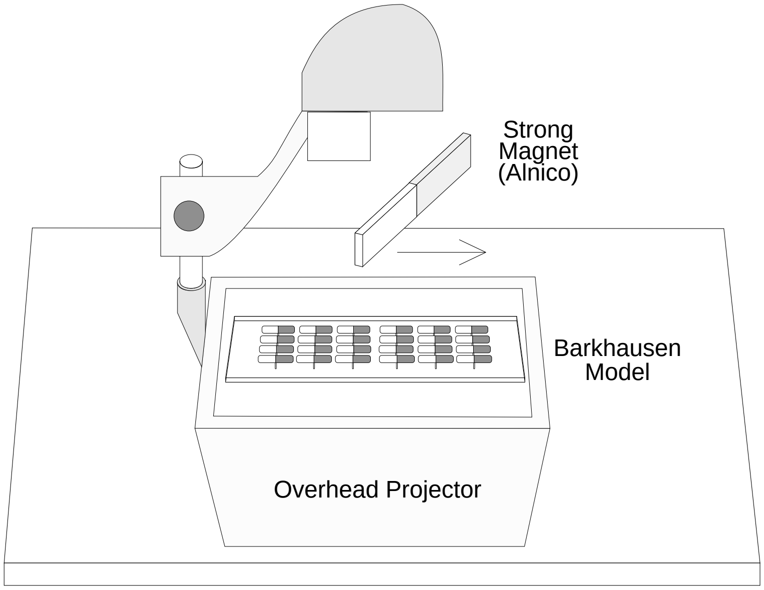
Barkhausen effect: Magnet and coil with soft iron core.

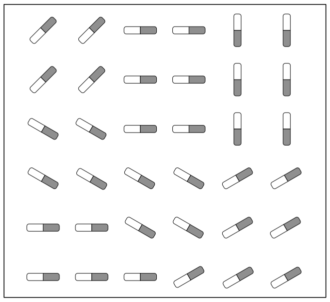


A soft iron rod or core is placed within a long cylindrical coil made of many turns of fine wire. When a strong magnet is brought up to the closed end of the rod, various regions of iron within the rod (magnetic domains) shift to orient with the field of the magnet. The abruptly changing magnetic field associated with each shifting region cuts across nearby coils of wire, generating a current. The current is amplified and sent to a speaker. Sharp, crackling noises can be heard, representing the re-orientation of iron molecules in the rod. If the iron core is removed, and the magnet is moved across the coils, there is no noise from the speaker.

MAGNETIC PROPERTIES. D+35+7

Barkhausen effect model: Many tiny magnets on pivots on overhead projector.





Projection

This model is a mechanical analogy of the Barkhausen effect. Many small magnets are arranged on needle-points mounted on a clear Lucite base that can be placed on an overhead projector. A large Alnico bar magnet is waved over the model, and the model magnets are put in motion. The model magnets settle down in various patterned 'magnetic domains'.

MAGNETIC PROPERTIES. D+35+8

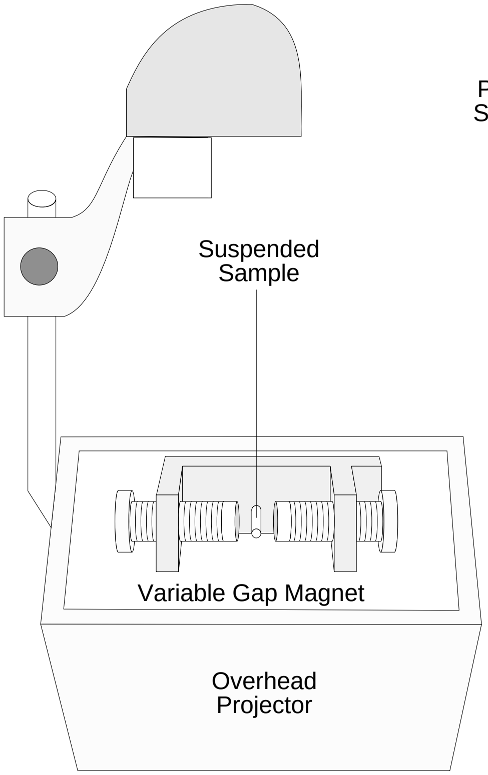
Film: Ferromagnetic Domains,-by Kittel and Williams, at Bell Labs.

Film Title: Ferromagnetic Domains.
Level: Upper elementary-Adult.
Length: 20.5 minutes. Black and white. No sound.

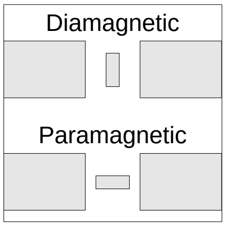
In this film, silicon-iron and various other magnetic materials (such as alnico) are subjected to changing magnetic fields. The shifting in the domain boundaries, and the change in the size, shape, and orientation of the small magnetic domains is observed. The technique of dusting the material with magnetite (Fe_3O_4) is shown: the magnetite collects on domain boundaries, where the lines of the magnetic field cut the surface. Magnetic hysteresis is discussed, along with the presence of 'spike' domains forming around defects in the materials. The sudden snapping of spikes under the application of a magnetic field, the Barkhausen effect, is shown.

MAGNETIC PROPERTIES. D+35+9

Para and Diamagnetic materials in magnetic field with OHP.



Projected Image of
Suspended Sample



Various paramagnetic and diamagnetic materials (about 1.5 cm. long) are suspended on a silk thread between the poles of a variable gap magnet (neodymium, very strong). Paramagnetic samples will align with the magnet poles. Diamagnetic samples will swing away from the poles. Paramagnetic samples include: aluminum (+16.5), potassium dichromate (+29.4), platinum (+201.9), and liquid oxygen (+7699). Diamagnetic samples include: copper (-5.46), carbon (-6), zinc (-11.4), silver (-19.5), lead (-23.0), and bismuth (-280.1). (The numbers are the magnetic susceptibility x 10^{-6} cgs).

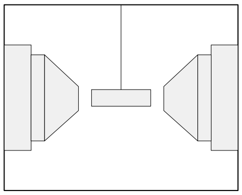
Paramagnetic materials have a net permanent magnetic dipole moment. When a magnetic field is applied, the alignment of the electron orbits in the material actually increases the field somewhat, causing the sample to align with the field. Paramagnetic materials also exhibit diamagnetism, but the paramagnetic effect is much larger. Rising temperature can destroy the paramagnetic effect, and just leave the diamagnetism.

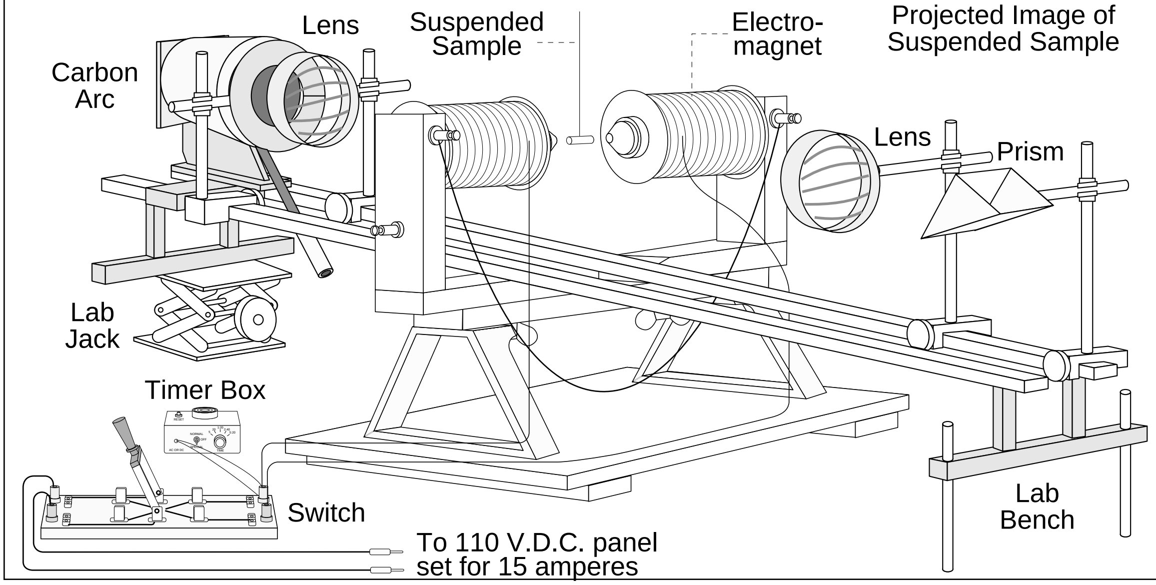
Diamagnetism is present in all materials, and is weaker than paramagnetism. When a magnetic field is applied, the electron orbits are realigned so that the magnetic field is actually weakened (an atomic-scale consequence of the Lenz law of induction), and the sample swings away from the direction of the main field.

MAGNETIC PROPERTIES. D+35+10

Paramagnetic and diamagnetic materials in magnetic field with arc lamp.

Various paramagnetic and diamagnetic materials (about 1.5 cm. long) are suspended on a silk thread between the poles of an electromagnet. A large current (about 15 amps) is sent through the electromagnet coils. Paramagnetic samples will align with the magnet poles. Diamagnetic samples will swing away. Samples available are: Alum, aluminum, bismuth, carbon, copper, glass, iron, lead, nickel, potassium dichromate, silver, tin, and zinc, (and liquid oxygen, with caution, on request). Care should be taken to not leave the electromagnet on for very long (15 sec.).


Projected Image of Suspended Sample

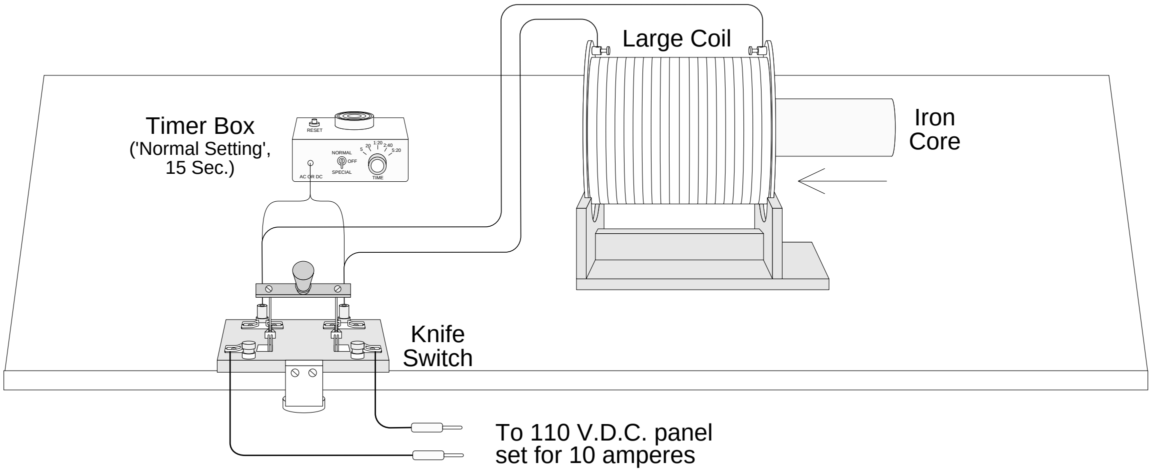


MAGNETIC PROPERTIES. D+35+12

Linear motor: An iron core jumps into a solenoid.

Throughout the technical world, the solenoid motor has been used for mechanical controls. Typical examples are the electric clutch in automobile air conditioners, transmission shifters in washing machines, and electric door latches on the entrances to apartment buildings.

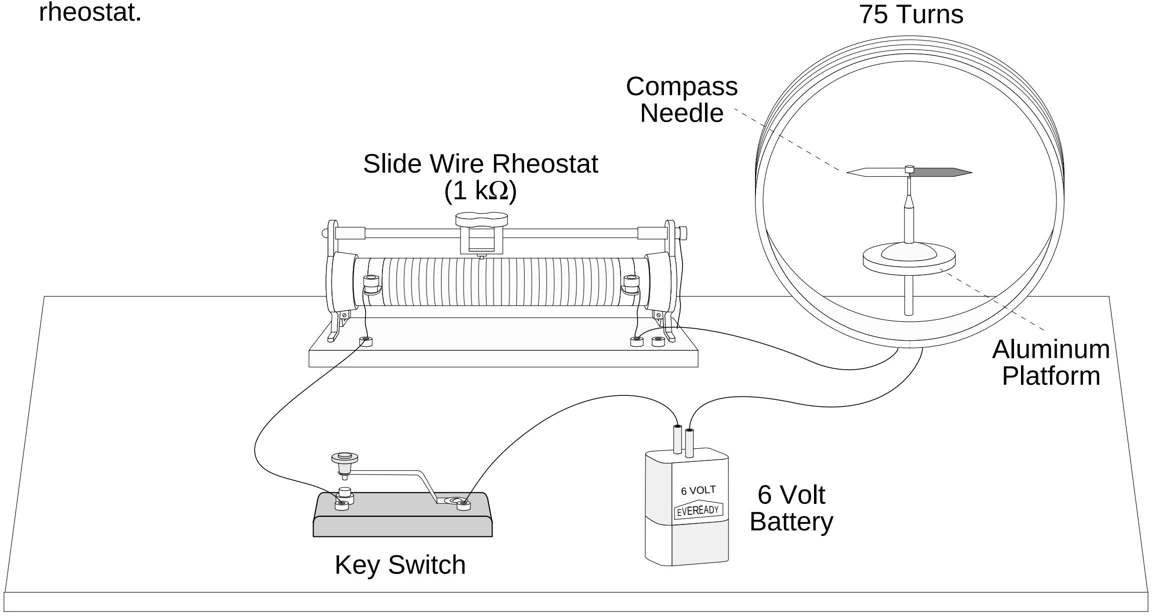
To operate the demonstration, slide the core about halfway into the coil, then apply power. The core will be vigorously drawn into the center of the coil. With power still on, demonstrate that the core cannot be withdrawn. Turn off the power, and remove the core easily. The timer box alerts the operator to turn power off before the coil roasts.



METERS. **D+40+0**

Tangent galvanometer: Compass needle pivots in a coil.

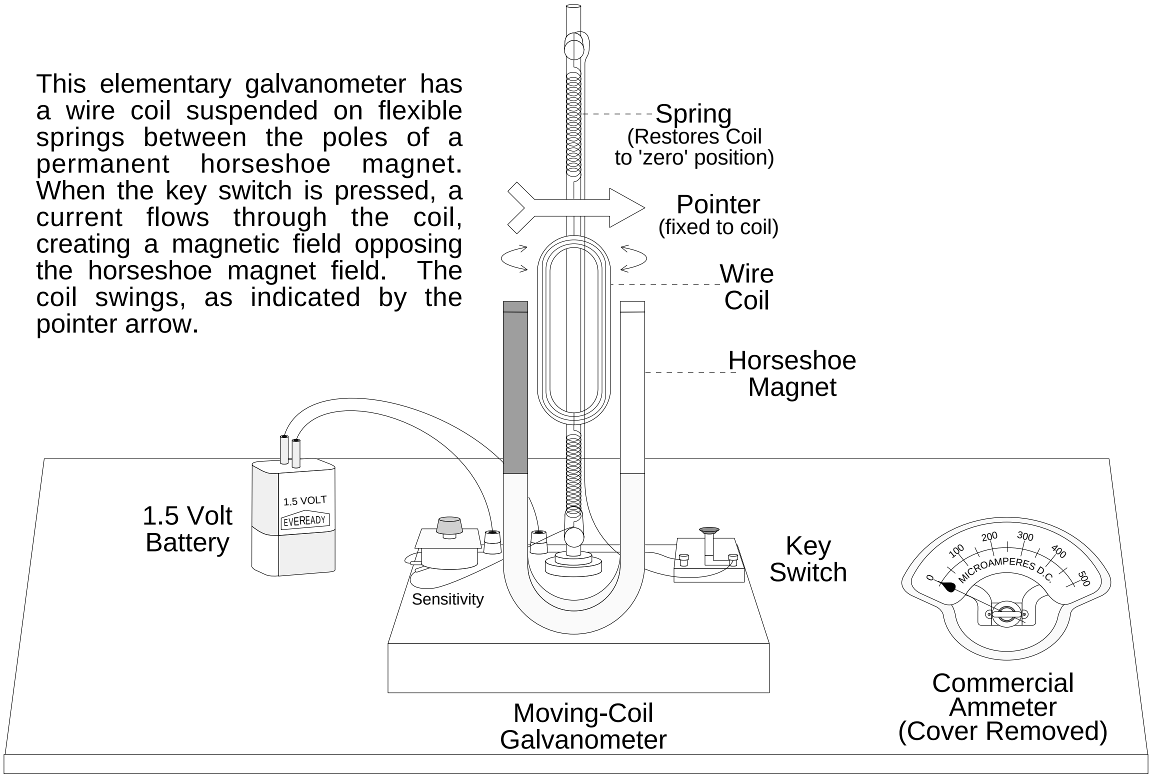
This is a simple galvanometer. A compass needle is placed inside a 25 cm. diameter coil of wire. When a key switch is pressed, current flows through the coil, producing a magnetic field. The compass will swing to a new position, depending on the coil current. The current in the coil is adjusted using the rheostat.



METERS. **D+40+2**

Elementary galvanometer: Coil on spring in magnetic field.

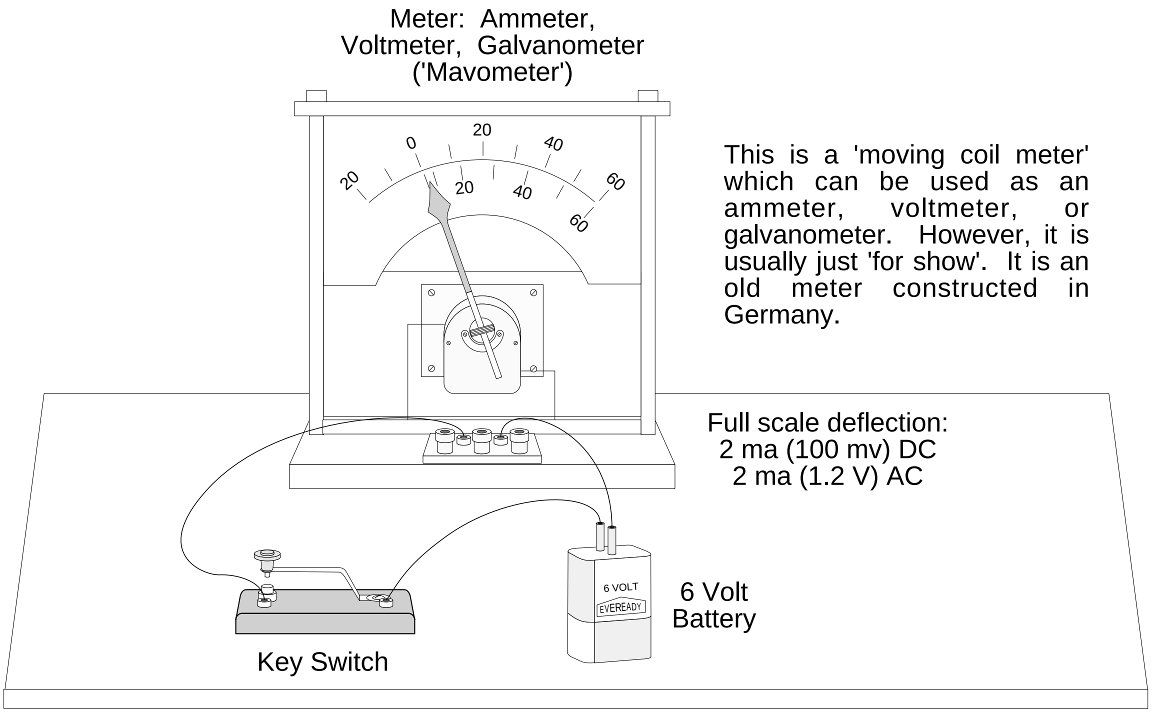
This elementary galvanometer has a wire coil suspended on flexible springs between the poles of a permanent horseshoe magnet. When the key switch is pressed, a current flows through the coil, creating a magnetic field opposing the horseshoe magnet field. The coil swings, as indicated by the pointer arrow.



METERS.

D+40+4

Mavometer: Ammeter / voltmeter / galvanometer.



This is a 'moving coil meter' which can be used as an ammeter, voltmeter, or galvanometer. However, it is usually just 'for show'. It is an old meter constructed in Germany.

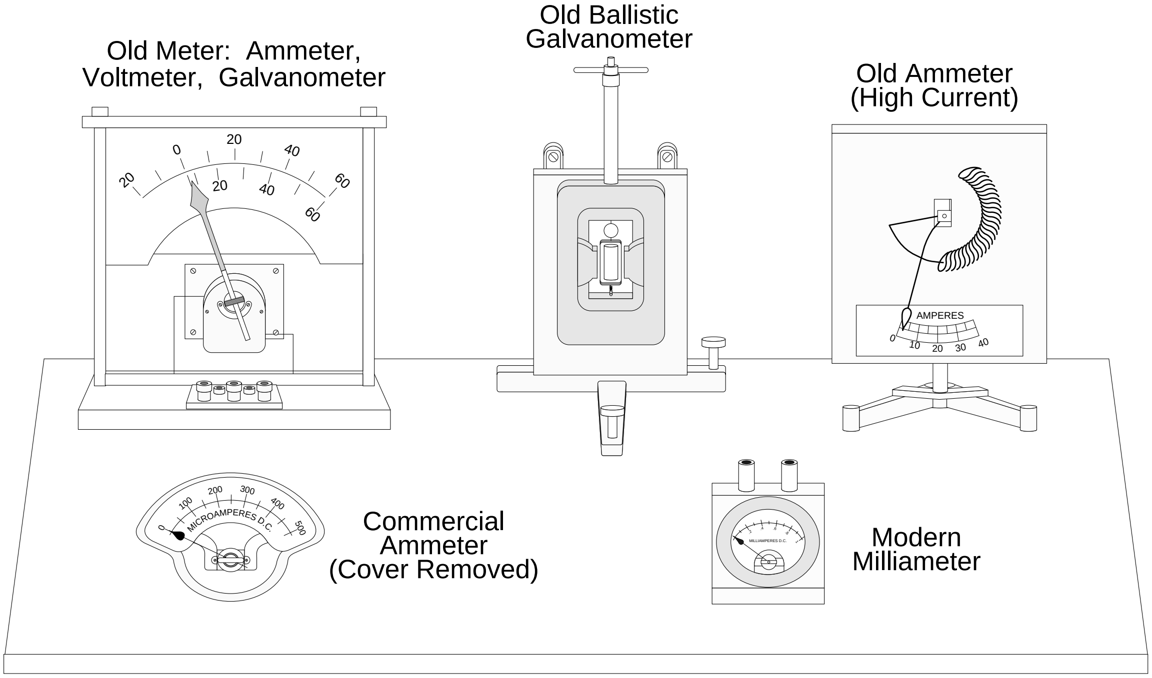
Full scale deflection:
2 ma (100 mv) DC
2 ma (1.2 V) AC

METERS.

D+40+6

Various meters for display.

There are numerous ammeters for display, some old and some new. There are more available than are shown in the drawing.

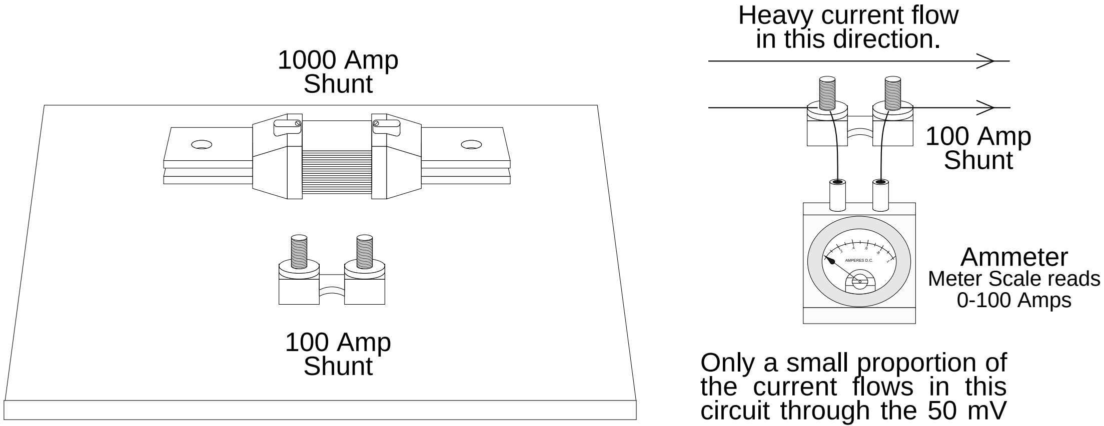


METERS.

D+40+8

Ammeter shunt: Only a small current flows to the meter.

There are several ammeter shunts for display. They are made of copper, and are constructed so as to radiate a lot of heat. In a circuit with a large current, most of the current goes through the shunt, and a small amount goes through the ammeter. Thus, a sensitive low-current meter can be used to measure large current flows.



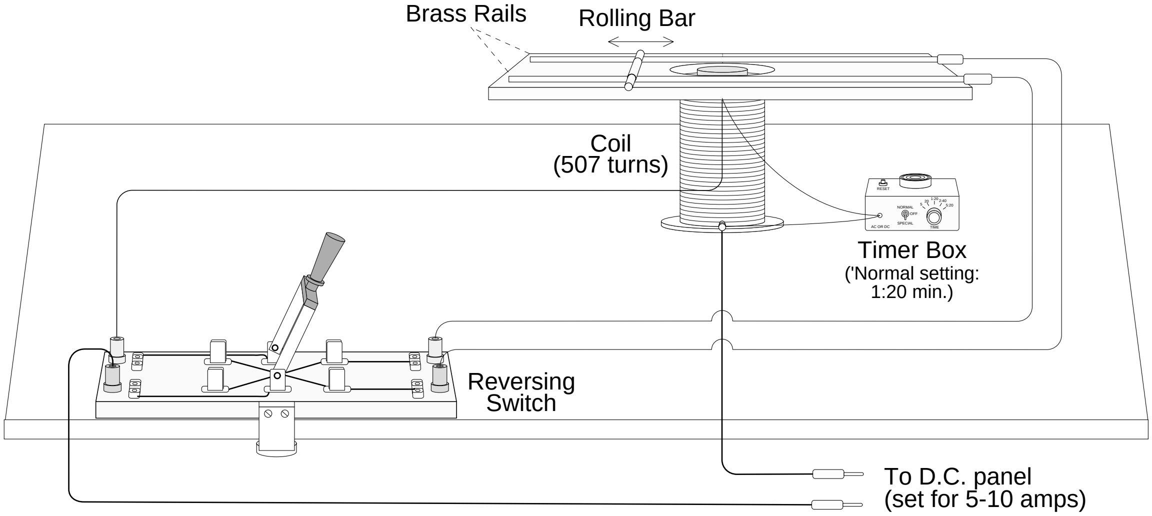
Only a small proportion of the current flows in this circuit through the 50 mV meter movement.

MOTORS.

D+45+0

Rolling bar motor: Bar rolls on rails over solenoid with core.

(Same as D+30+20)

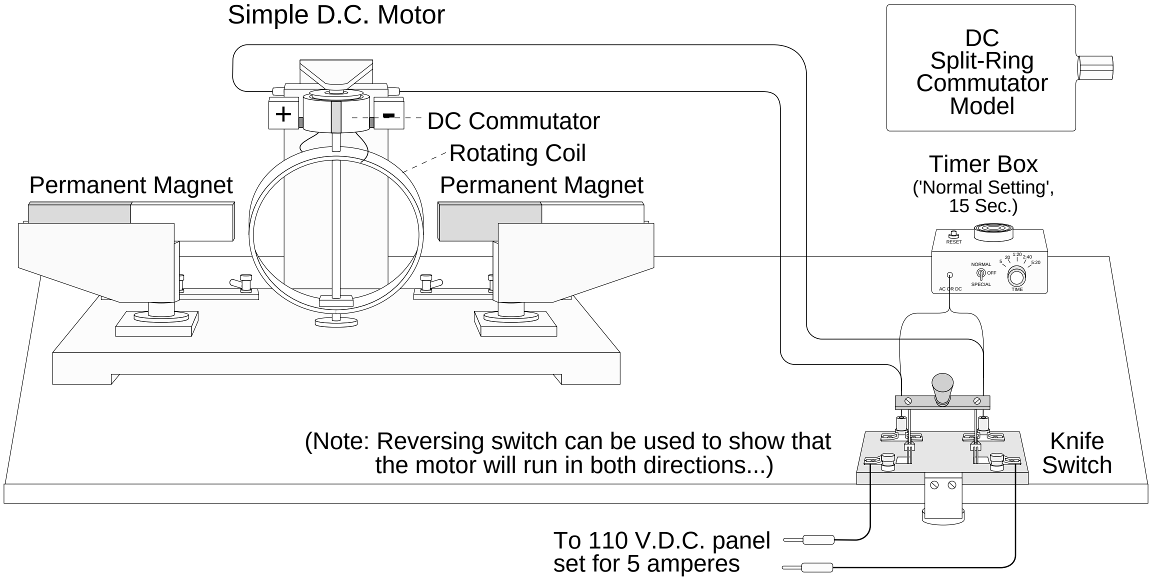


This is a simple motor. Throwing the 'reversing switch' one way sends about five amps of current (D.C.) through a large coil of wire, with a soft iron core inserted within. At the same time, current flows through two parallel brass rails and across a moveable brass bar. The field of the coil (enhanced by the core) either attracts or repels the magnetic field generated by the current flowing through the moveable bar. The bar rolls left or right. Throwing the switch in the opposite direction causes the bar to roll in the opposite direction. (The two rails and bar must be polished to insure good conduction.)

The Timer box reminds the demonstration operator to turn off the apparatus in about a minute to avoid damage to the coil.

MOTORS. D+45+2

Elementary spit-ring armature DC motor. (D+15+6 as a motor).

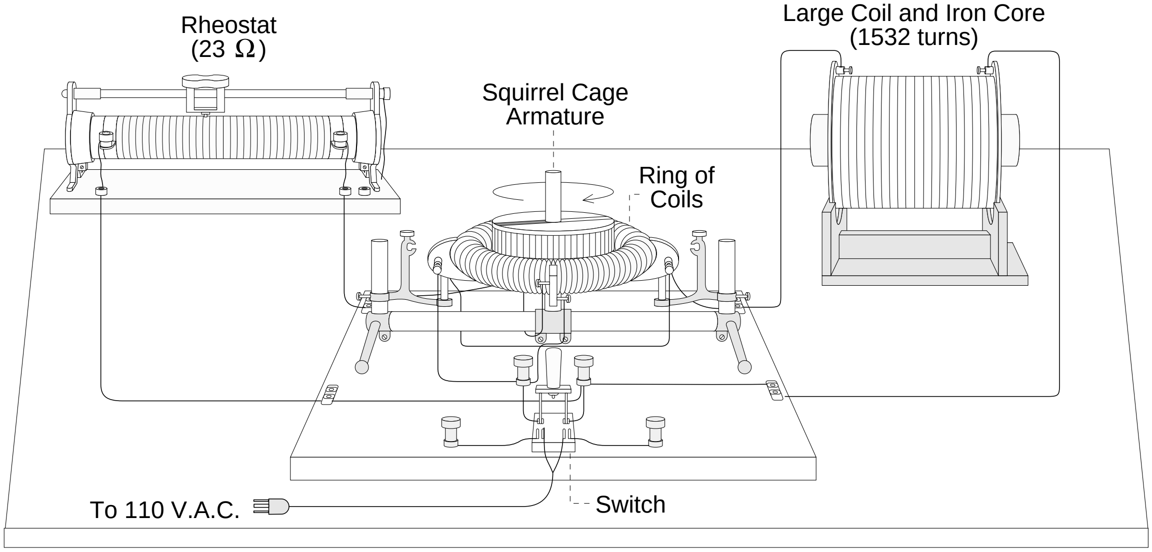


A coil, free to rotate about a vertical axis, is mounted within a stationary magnetic field produced by two strong permanent bar magnets. Closing a knife switch sends current through the coil. The field produced by the coil swings the coil to line up with the permanent magnet field. However, just as the two fields become aligned, the coil 'split-ring' commutator causes the coil current and magnetic field to reverse, causing the coil to be repelled away from the bar magnets. The cycle then repeats, and the coil continues to revolve.

The timer box beeps to alert the operator to turn off power to avoid burning up the motor.

MOTORS. D+45+4

AC induction motor: Armature in a whirling field.



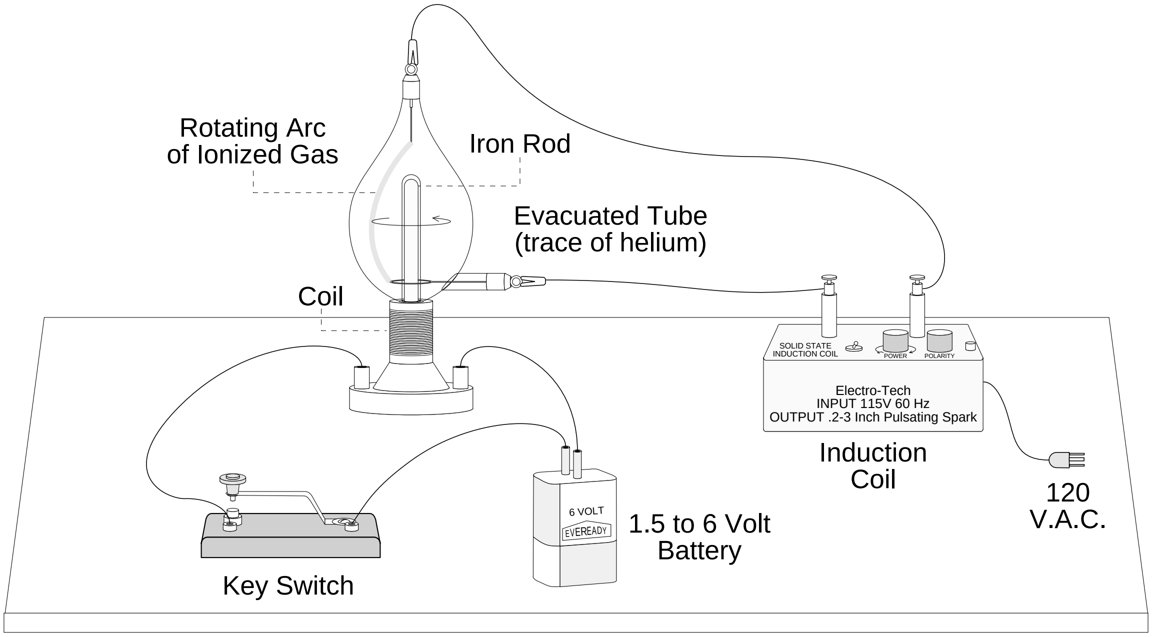
This is an old AC induction motor with casing removed. Throwing the switch causes a rotating field in the ring of coils. The rotating field induces eddy currents in the squirrel cage armature. The armature eddy currents produce magnetic fields in a direction opposite to the rotating coil field. This causes the armature to rotate without any electrical connection between the coils and the armature. The speed of rotation can be varied by sliding the core in or out of the coil, or by varying the rheostat.

The armature can be removed, and a piece of frosted glass laid on the top of the ring of coils. Iron filings sprinkled on the glass whirl in a circle when the A.C. is turned on.

MOTORS. D+45+6

Elementary motor: Electron beam revolves in magnetic field.

The glass tube in this apparatus is evacuated, with a trace of helium added. A large D.C. voltage is placed across the tube terminals, creating an arc of glowing ionized gas. When a key-switch is pressed, a current flows through a coil at the base of the tube, creating a magnetic field in an iron rod that extends up into the tube. The magnetic field is at an angle to the current in the arc of glowing gas, causing the glowing arc to rotate.

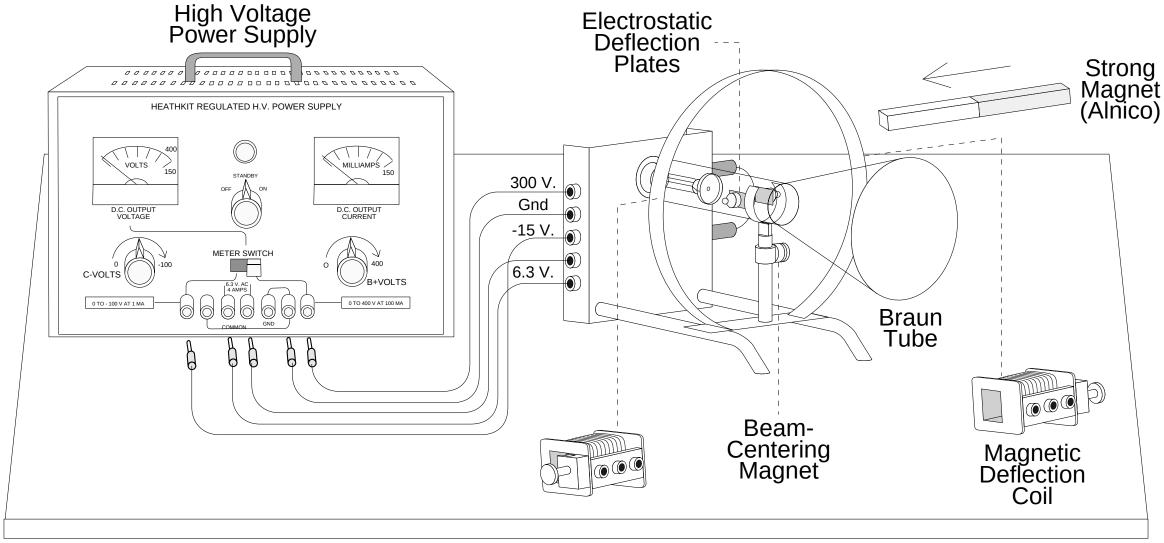


OSCILLOSCOPES. D+50+0

The Braun tube with magnetic and electrostatic deflection.

The Braun tube is a cathode ray tube. Electrons are emitted from a heated cathode (6.3 V.), focused (-15V.), then accelerated through a barrel anode (300 V.) and hit a flourescent screen. The beam position can be adjusted with a small centering magnet. For demonstration purposes, the beam can be deflected magnetically either with a hand-held permanent magnet or with magnetic deflection coils powered with a 0-12 VDC power supply. The beam can also be deflected electrostatically, using a high-voltage generator.

This tube is reliable, but must be given a warm-up time of about 5 minutes.

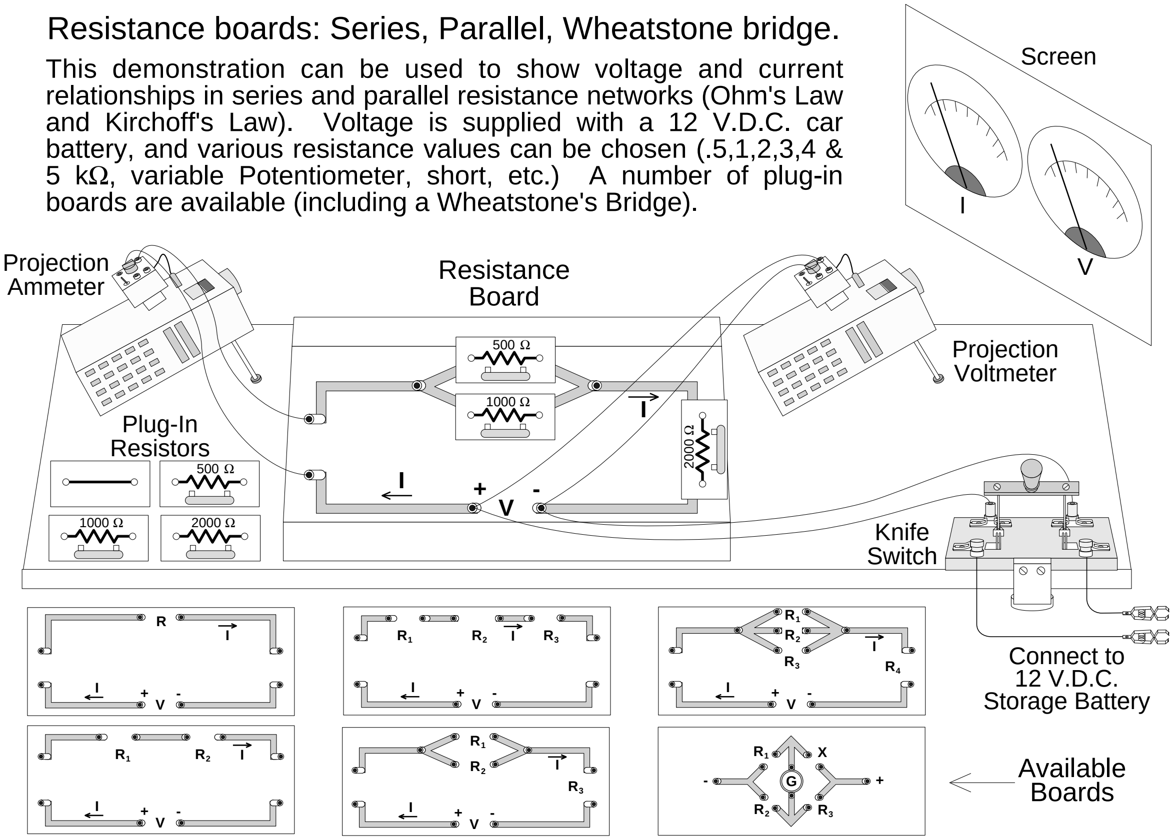


RESISTANCE.

D+55+0

Resistance boards: Series, Parallel, Wheatstone bridge.

This demonstration can be used to show voltage and current relationships in series and parallel resistance networks (Ohm's Law and Kirchoff's Law). Voltage is supplied with a 12 V.D.C. car battery, and various resistance values can be chosen (.5,1,2,3,4 & 5 kΩ, variable Potentiometer, short, etc.) A number of plug-in boards are available (including a Wheatstone's Bridge).

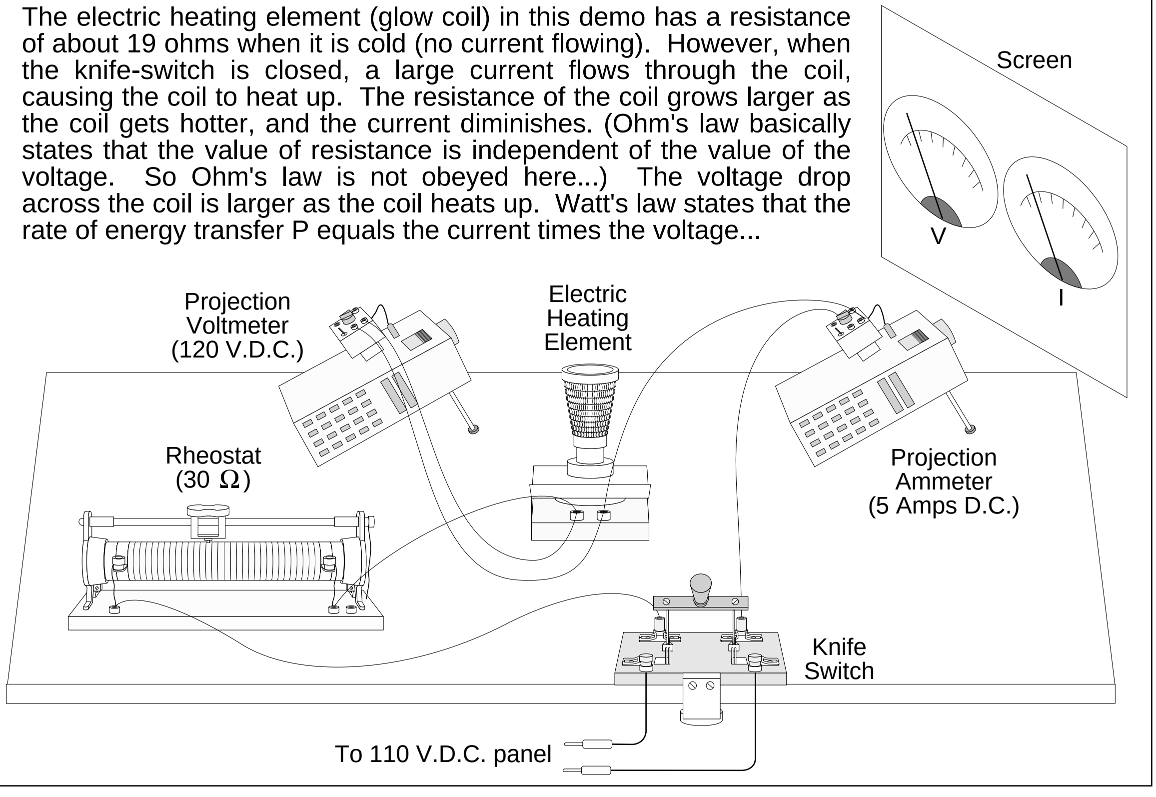


RESISTANCE.

D+55+2

Watt's Law: Variable resistor, glow coil, volt and amp meter.

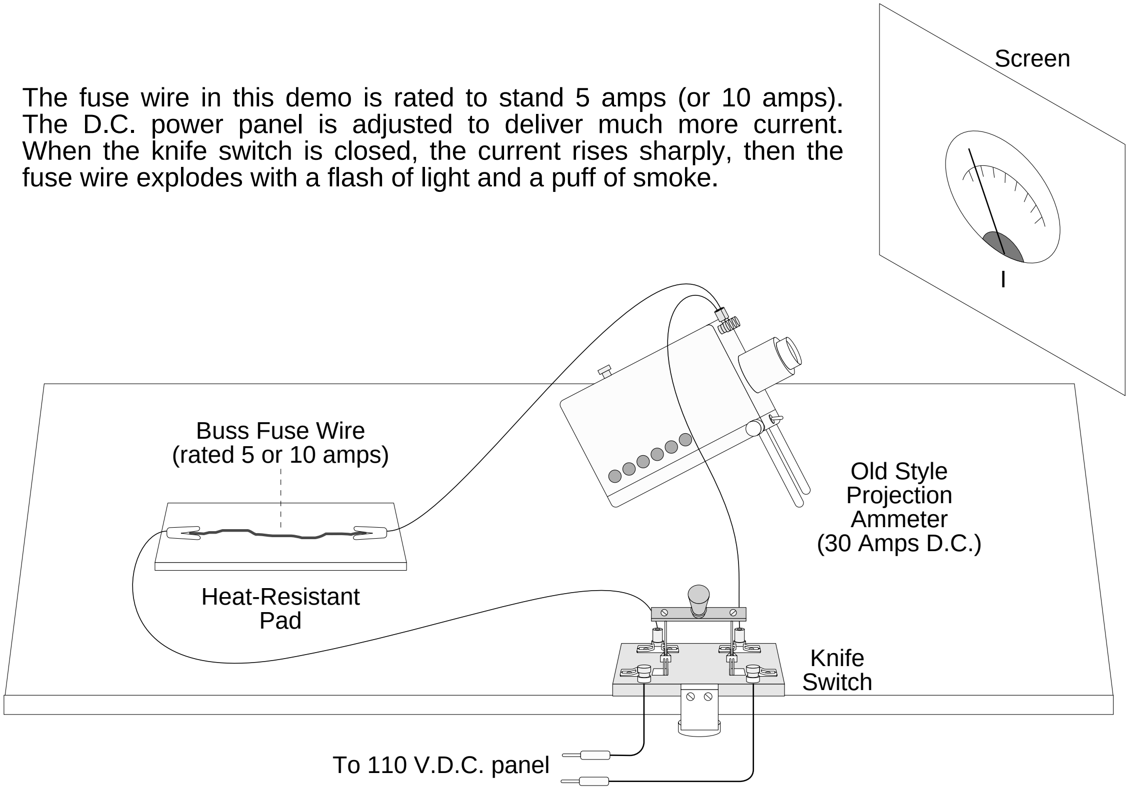
The electric heating element (glow coil) in this demo has a resistance of about 19 ohms when it is cold (no current flowing). However, when the knife-switch is closed, a large current flows through the coil, causing the coil to heat up. The resistance of the coil grows larger as the coil gets hotter, and the current diminishes. (Ohm's law basically states that the value of resistance is independent of the value of the voltage. So Ohm's law is not obeyed here...) The voltage drop across the coil is larger as the coil heats up. Watt's law states that the rate of energy transfer P equals the current times the voltage...



RESISTANCE. D+55+4

High current melts the fuse wire.

The fuse wire in this demo is rated to stand 5 amps (or 10 amps). The D.C. power panel is adjusted to deliver much more current. When the knife switch is closed, the current rises sharply, then the fuse wire explodes with a flash of light and a puff of smoke.

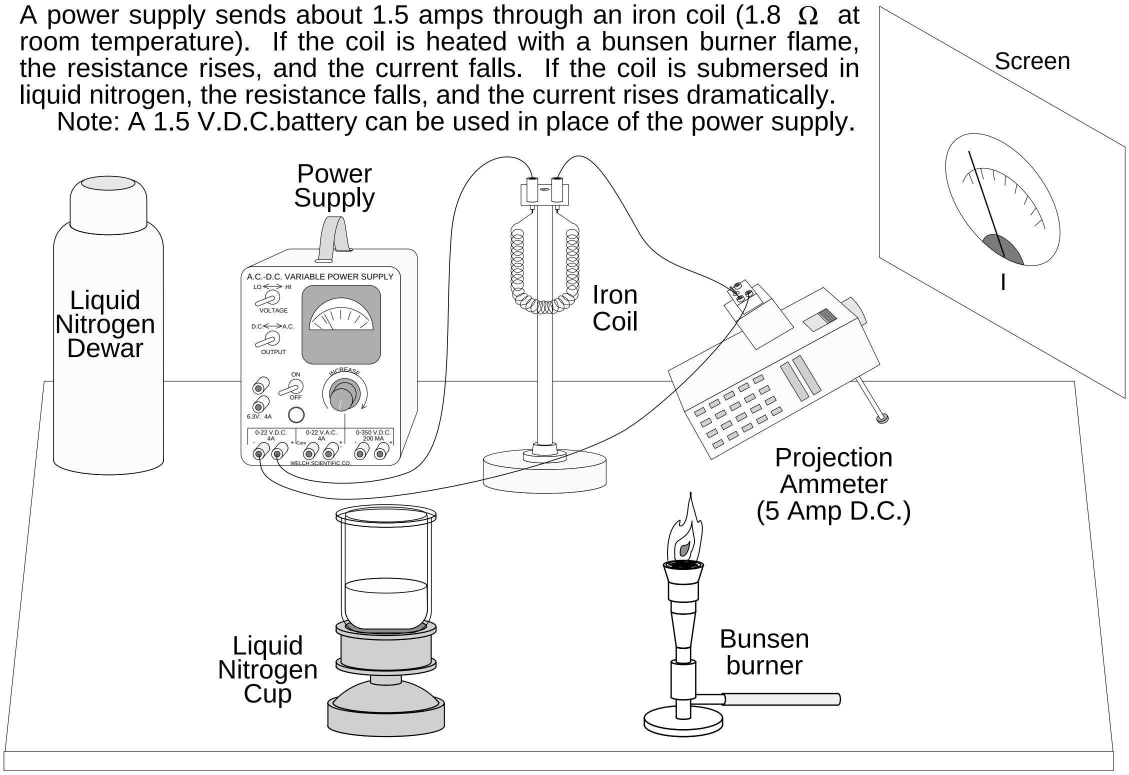


RESISTANCE. D+55+6

Resistance thermometer: Iron coil in liquid nitrogen or flame varies current.

A power supply sends about 1.5 amps through an iron coil (1.8 Ω at room temperature). If the coil is heated with a bunsen burner flame, the resistance rises, and the current falls. If the coil is submersed in liquid nitrogen, the resistance falls, and the current rises dramatically.

Note: A 1.5 V.D.C.battery can be used in place of the power supply.

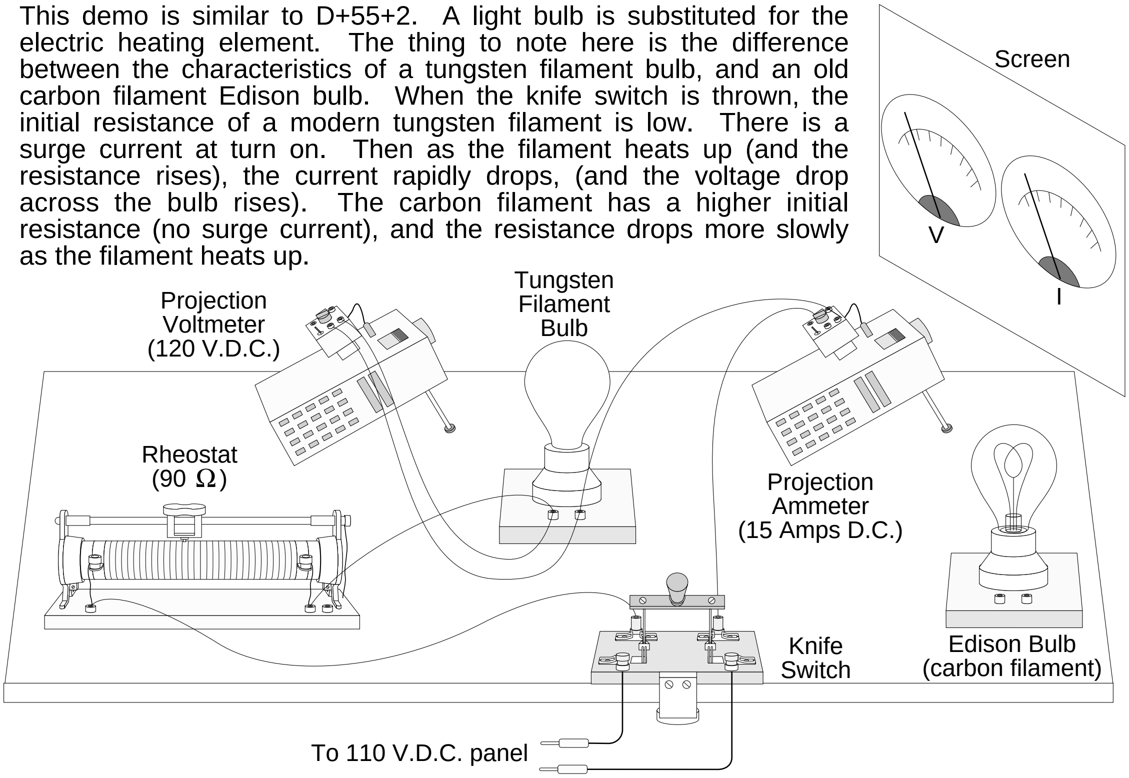


RESISTANCE.

D+55+8

Effect of temperature on current in carbon or tungsten filaments.

This demo is similar to D+55+2. A light bulb is substituted for the electric heating element. The thing to note here is the difference between the characteristics of a tungsten filament bulb, and an old carbon filament Edison bulb. When the knife switch is thrown, the initial resistance of a modern tungsten filament is low. There is a surge current at turn on. Then as the filament heats up (and the resistance rises), the current rapidly drops, (and the voltage drop across the bulb rises). The carbon filament has a higher initial resistance (no surge current), and the resistance drops more slowly as the filament heats up.

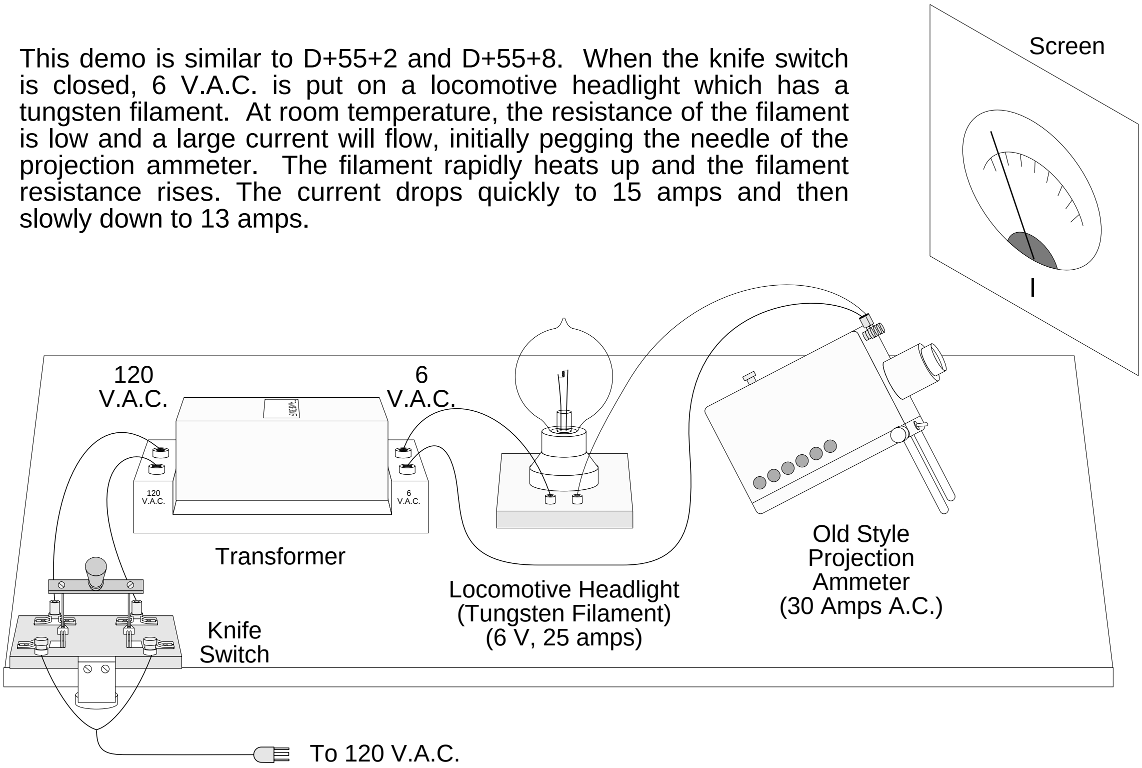


RESISTANCE.

D+55+10

Large tungsten filament lamp. As it heats, current drops.

This demo is similar to D+55+2 and D+55+8. When the knife switch is closed, 6 V.A.C. is put on a locomotive headlight which has a tungsten filament. At room temperature, the resistance of the filament is low and a large current will flow, initially pegging the needle of the projection ammeter. The filament rapidly heats up and the filament resistance rises. The current drops quickly to 15 amps and then slowly down to 13 amps.



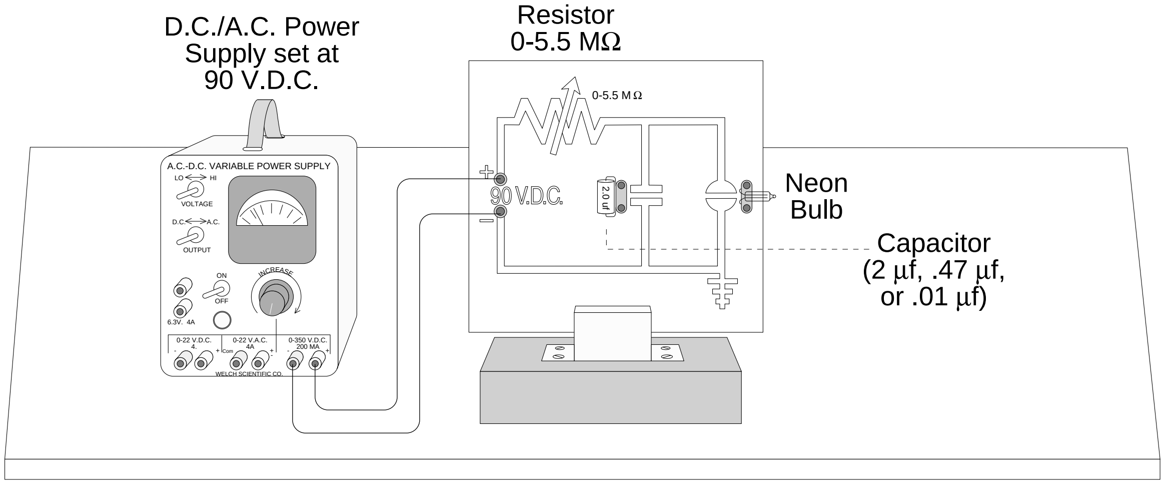
RESISTANCE

D+55+12

Oscillator made with resistor, capacitor and neon lamp.

Same as
D+0+30

90 Volts D.C. is put across a series RC circuit. A neon bulb is in parallel with the capacitor. When the capacitor charges up to 80 volts, the neon bulb flashes (breakdown voltage for this neon bulb is about 80 volts), draining the capacitor charge. The capacitor then begins to charge again, and the cycle repeats. The period T of the flashes of the bulb is the product of the Resistance and Capacitance (RxC). The resistance can be varied from 0 to 5.5 MΩ, and three different capacitors can be plugged in: 2 µf, .47 µf, and .01 µf.



RESISTANCE.

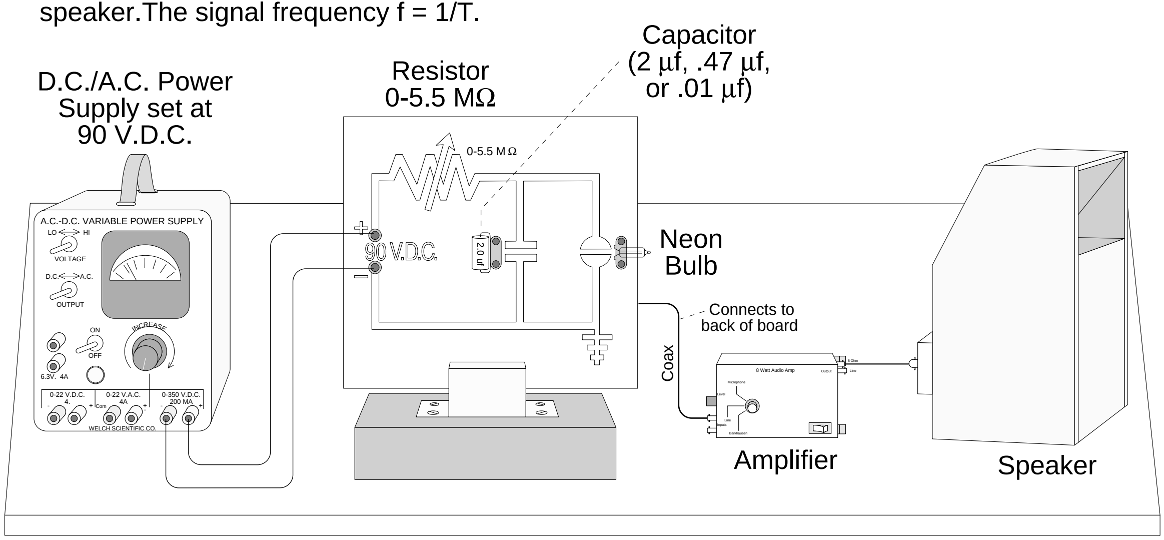
D+55+13

Same as D+55+12 using speaker for audio tone generation.

Same as
D+0+32

90 Volts D.C. is put across a series RC circuit. A neon bulb is in parallel with the capacitor. When the capacitor charges up to 80 volts, the neon bulb flashes (breakdown voltage for this neon bulb is about 80 volts), draining the capacitor charge. The capacitor then begins to charge again, and the cycle repeats. The period T of the flashes of the bulb is the product of the Resistance and Capacitance (RxC). The resistance can be varied from 0 to 5.5 MΩ, and three different capacitors can be plugged in: 2 µf, .47 µf, and .01 µf.

The oscillating signal produced in this demo is amplified and made audible with a speaker.The signal frequency f = 1/T.



RESISTANCE.

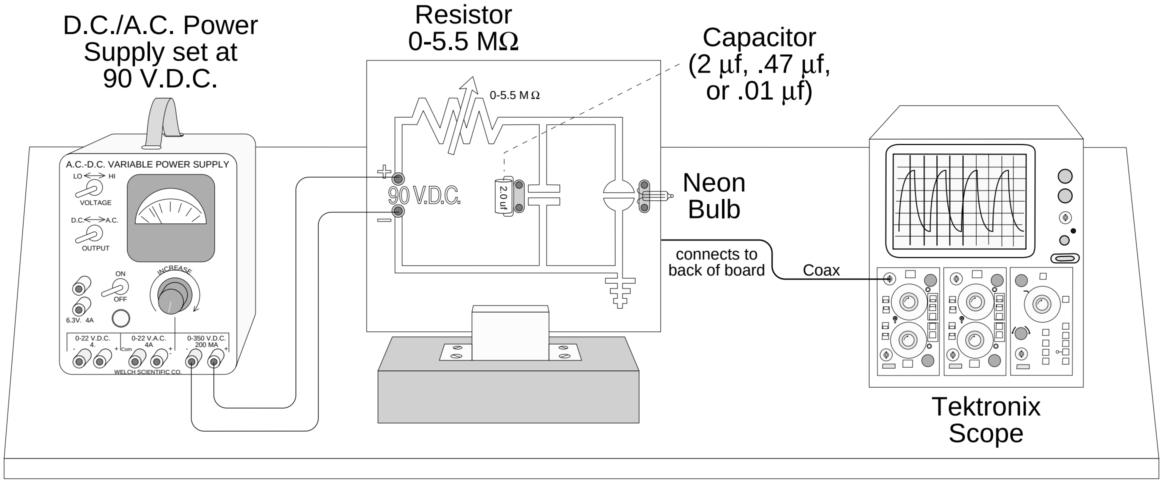
D+55+14

Same as D+55+12 using oscilloscope to display waveform.

Same as
D+0+34

90 Volts D.C. is put across a series RC circuit. A neon bulb is in parallel with the capacitor. When the capacitor charges up to 80 volts, the neon bulb flashes (breakdown voltage for this neon bulb is about 80 volts), draining the capacitor charge. The capacitor then begins to charge again, and the cycle repeats. The period T of the flashes of the bulb is the product of the Resistance and Capacitance (RxC). The resistance can be varied from 0 to 5.5 MΩ, and three different capacitors can be plugged in: 2 µf, .47 µf, and .01 uf.

The oscillating signal produced in this demo is displayed on an oscilloscope. The signal frequency f = 1/T. (A speaker can also be attached to make the signal audible, as in D+0+32.)



RESISTANCE.

D+55+16

Film: Elementary Electricity

Film Title: Elementary Electricity.
Level: Upper elementary-Adult.
Length: 8 minutes. Black and white. Sound.

This film is very simplistic,-perhaps too elementary for college students. It should be viewed before showing it to a class. It is a Navy film, (circa 1950?)

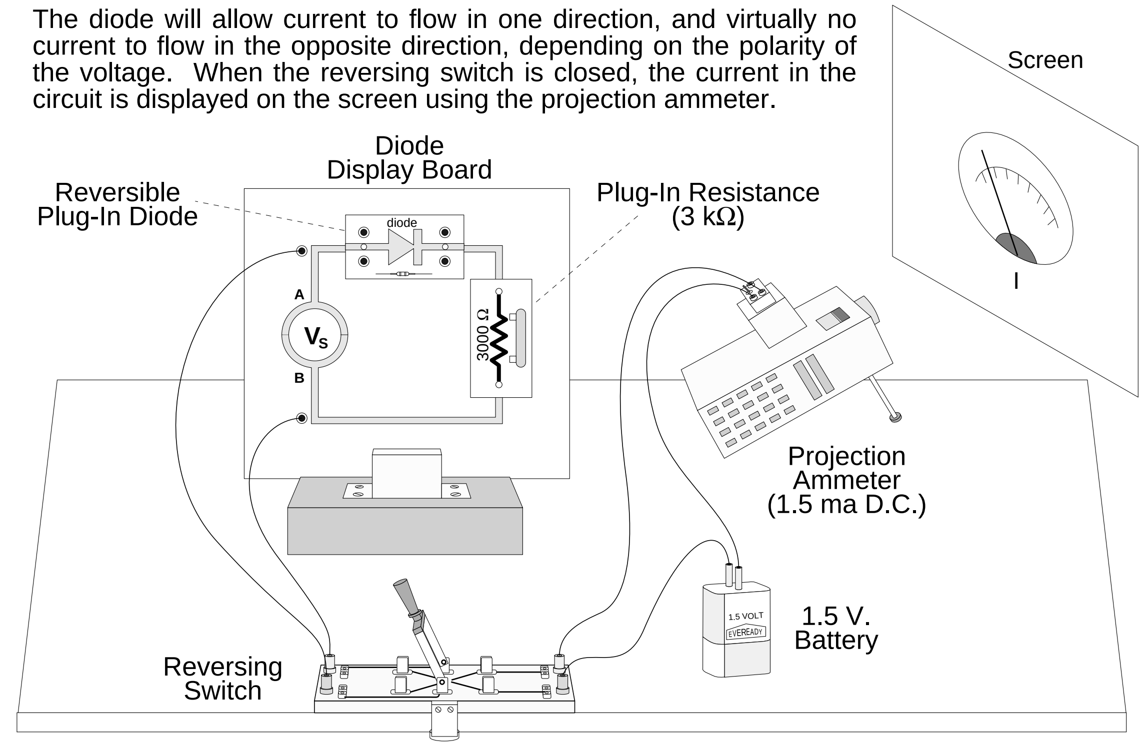
Current (coulombs), resistance (ohms), voltage (volts) are all defined. Simple circuits, with batteries in series, resistors, ammeters, and voltmeters are hooked up. Ohm's Law is defined. That's about it.

SOLID STATE AND SEMICONDUCTORS.

D+60+0

P-N Junction as a rectifier: Current flows one way.

The diode will allow current to flow in one direction, and virtually no current to flow in the opposite direction, depending on the polarity of the voltage. When the reversing switch is closed, the current in the circuit is displayed on the screen using the projection ammeter.

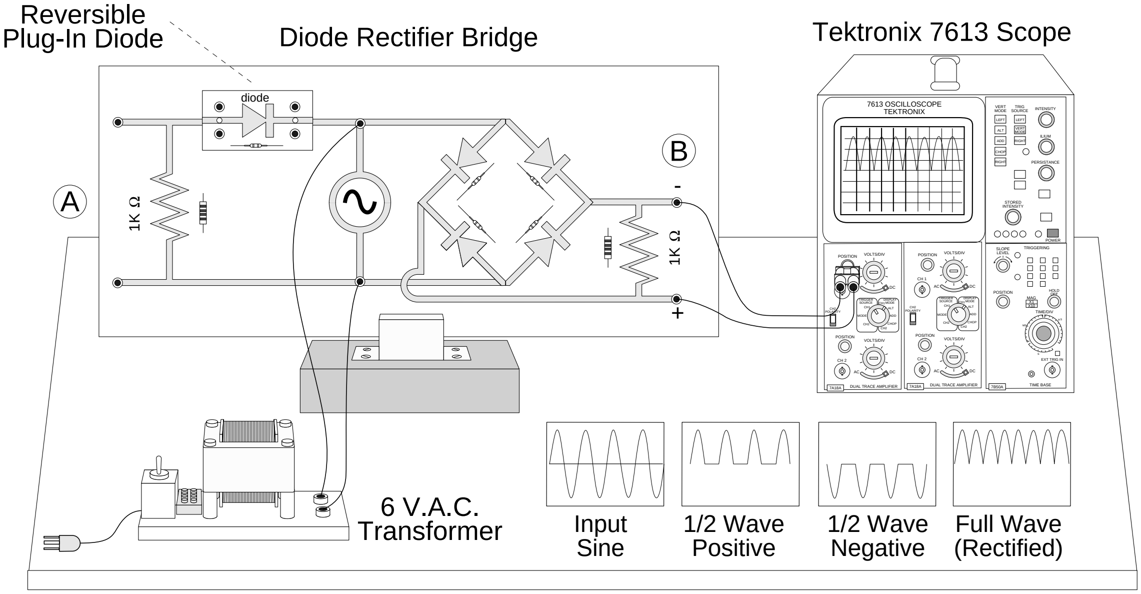


SOLID STATE AND SEMICONDUCTORS.

D+60+2

P-N Junction as a rectifier: Diode bridge rectifies AC voltage.

The diode will allow current to flow in one direction, and virtually no current to flow in the opposite direction, depending on the polarity of the voltage. In this demo, a 6 V.A.C. (sine wave) is injected into the circuit. The waveform at 'A' will be either a negative or positive 1/2 wave, depending on how the reversible diode is plugged in. The waveform at 'B', shown on the scope, will be a full-wave rectified signal (fluctuating D.C.).

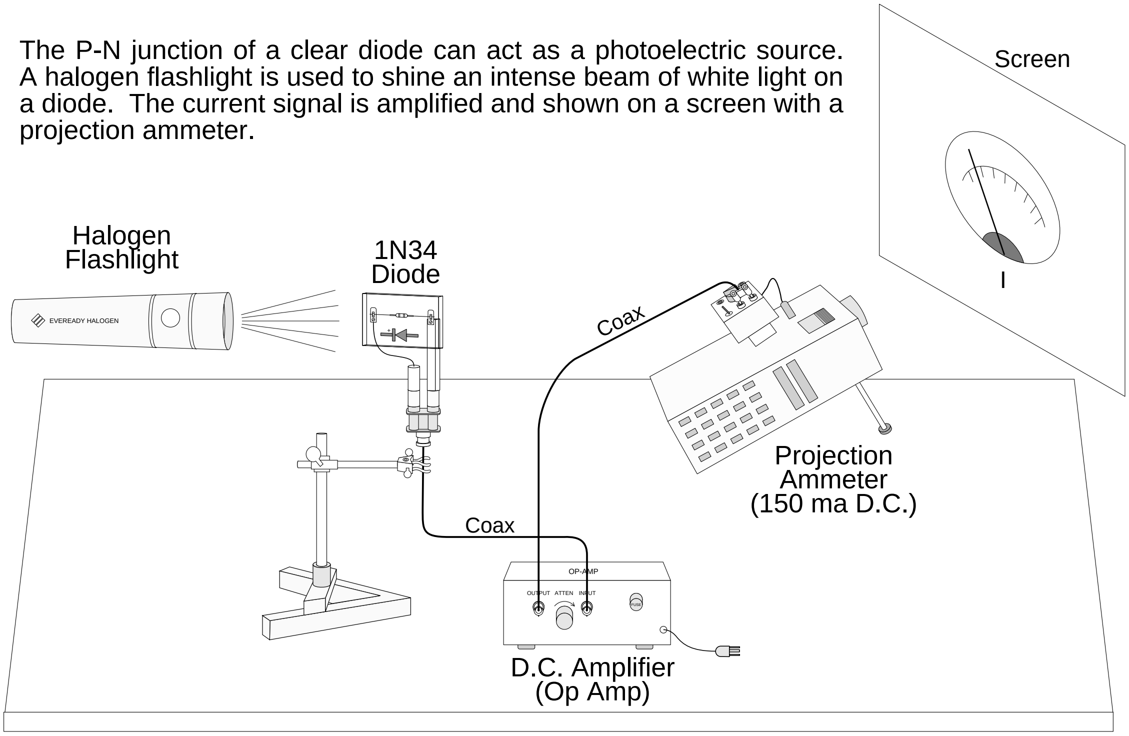


SOLID STATE AND SEMICONDUCTORS.

D+60+4

Photoelectric effect: Light on P-N junction causes current flow.

The P-N junction of a clear diode can act as a photoelectric source. A halogen flashlight is used to shine an intense beam of white light on a diode. The current signal is amplified and shown on a screen with a projection ammeter.

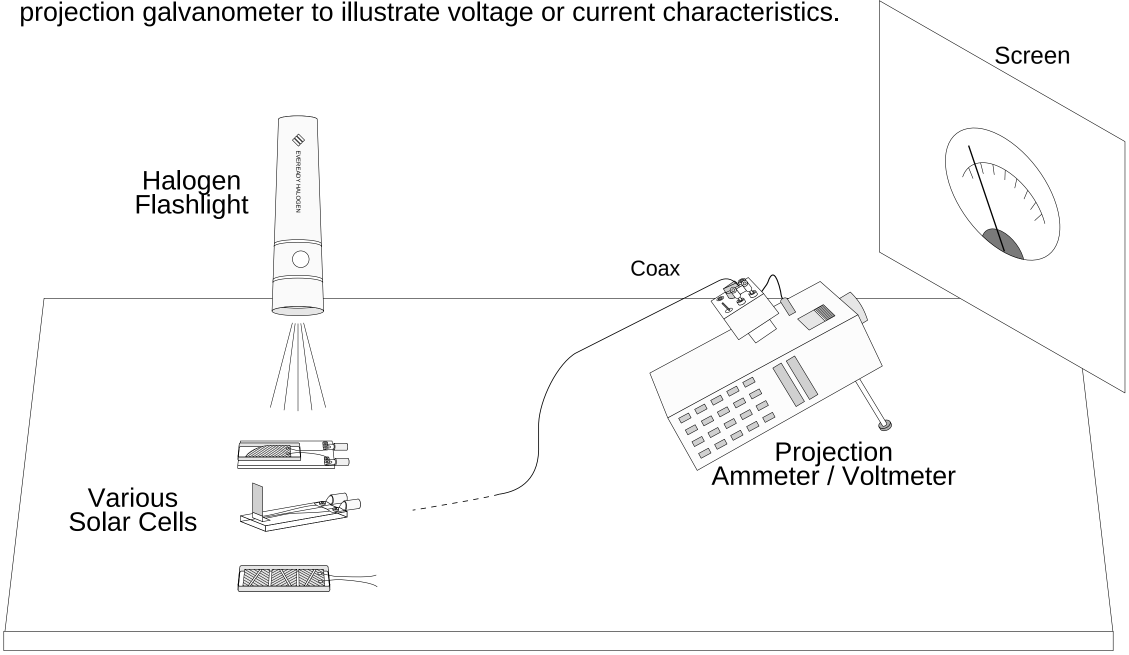


SOLID STATE AND SEMICONDUCTORS.

D+60+6

Several commercial solar cells.

Several types of solar cells (silicon cells, iron-selenium cells) are available for display. Photovoltaic cells convert incandescent light or sunlight directly into electrical energy. They can be hooked up to a projection galvanometer to illustrate voltage or current characteristics.



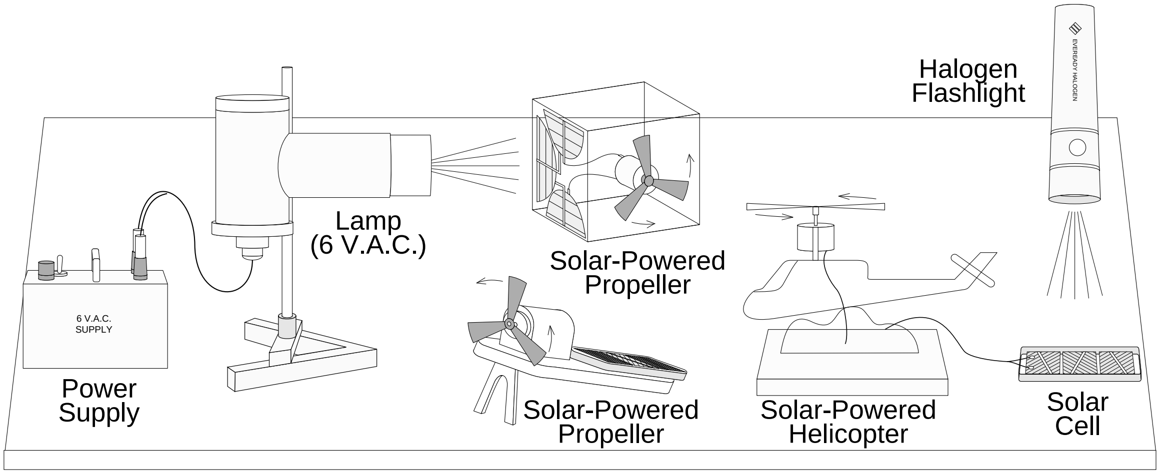
SOLID STATE AND SEMICONDUCTORS.

D+60+8

Solar energy demos: Solar cells spin a propeller using a light source.

There are several demonstrations that have motor-driven propellers powered by silicon solar cells. Perhaps the helicopter is the most visible in a large class.

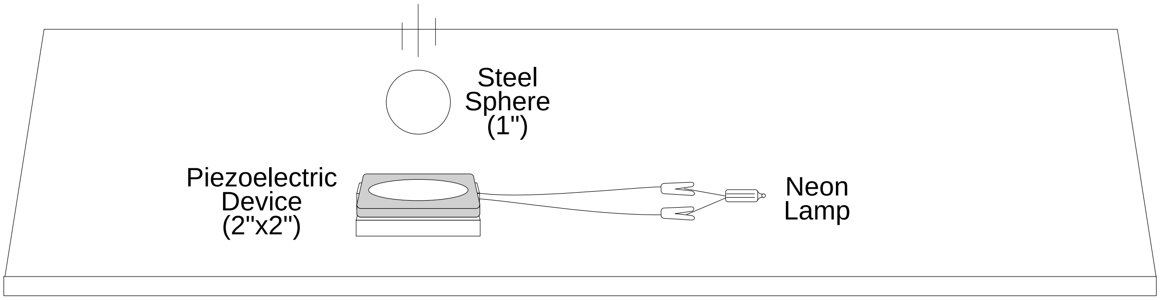
NOTE: There are many light sources that can be used to drive the motors. Some people prefer carbon arcs (very intense light), while others prefer smaller electric lamps or flashlights. For a greater effect, the light source can be placed about ten feet away from the solar-driven motor. Consult with the demonstration staff...



SOLID STATE AND SEMICONDUCTORS.

D+60+10

Piezoelectric Effect: crystal subjected to mechanical force produces voltage.



This piezoelectric device consists of a thin slice of polished quartz attached to a brass disk with two attached leads. A neon lamp serves as an indicator of electrical flow.

A piezoelectric crystal is a crystal which, when subjected to a mechanical force, produces a voltage (direct piezoelectric effect). Conversely, a mechanical force will be created if sufficient voltage is applied to the crystal (converse piezoelectric effect). Applying pressure to the crystal creates a potential difference within the crystal (that is, areas where electrons are in excess, and areas where they are in deficit). Such a potential difference is relieved by movement of electrons. Thus, when wires are attached to opposite sides of the stressed crystal, an electric current can flow.

A direct whack on the crystal, such as dropping a 1" steel ball bearing from about 1" height will cause the crystal to generate about 60 volts,-enough to briefly light the neon lamp (direct piezoelectric effect). Or slowly press on the disk, then slowly relieve the pressure: first one side of the lamp glows, then the other.

Attaching a signal generator to the leads and applying an a.c. signal causes the device to hum: it is a not very efficient speaker (converse piezoelectric effect). Connect the leads together, press on the crystal, then disconnect the leads before relaxing the pressure (creating an unrelieved potential difference). Then touch the leads together and you will hear a snap.

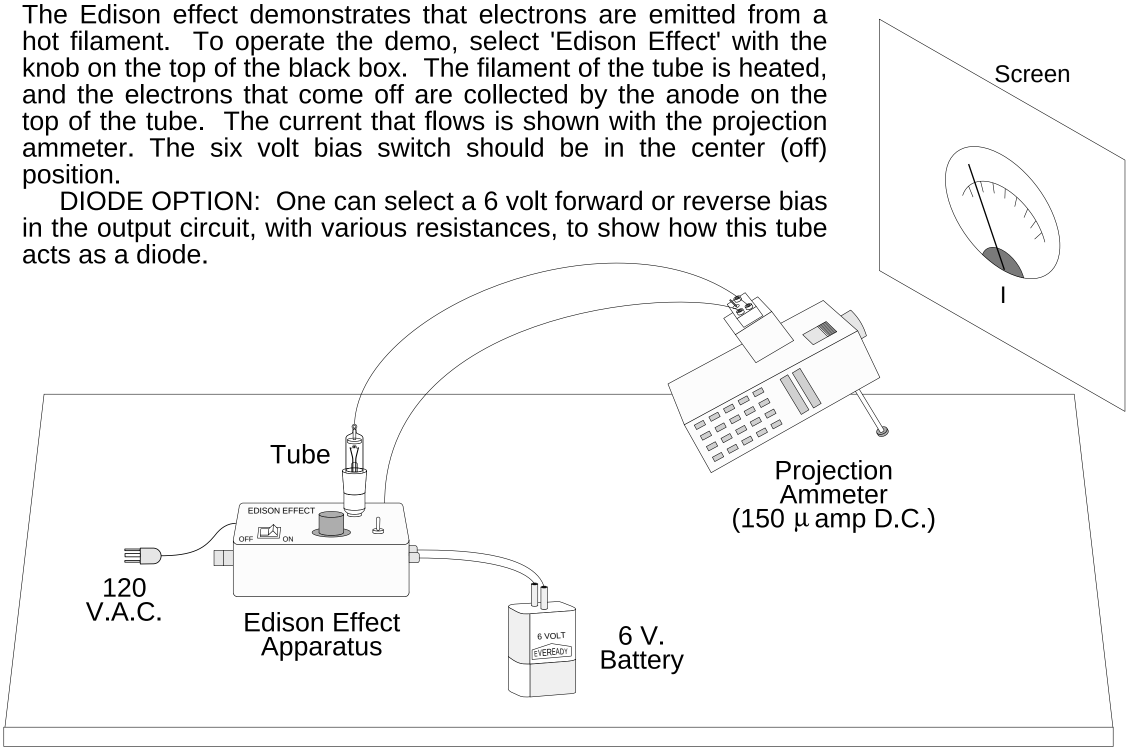
THERMIONIC EMISSION.

D+65+0

Edison effect: Electrons are cast off from hot filament.

The Edison effect demonstrates that electrons are emitted from a hot filament. To operate the demo, select 'Edison Effect' with the knob on the top of the black box. The filament of the tube is heated, and the electrons that come off are collected by the anode on the top of the tube. The current that flows is shown with the projection ammeter. The six volt bias switch should be in the center (off) position.

DIODE OPTION: One can select a 6 volt forward or reverse bias in the output circuit, with various resistances, to show how this tube acts as a diode.



THERMOELECTRICITY.

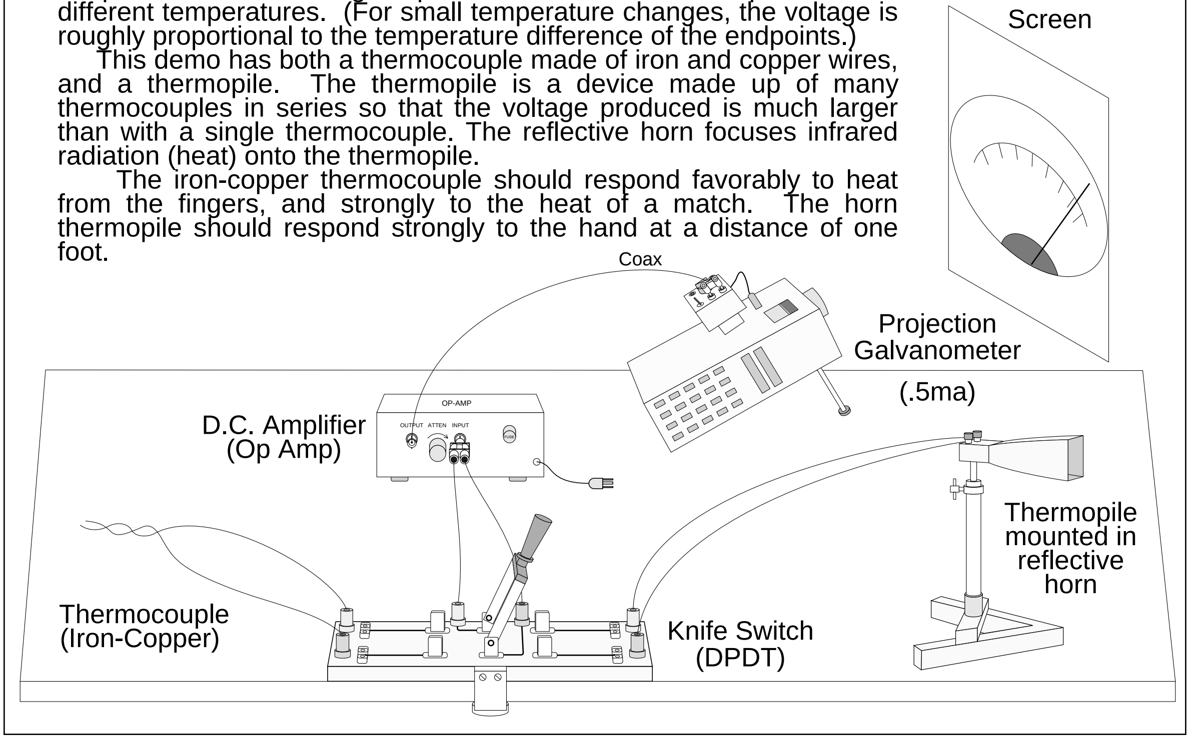
D+70+0

Thermocouple and thermopile, both make electricity from heat.

A thermocouple is formed when two dissimilar metals are joined at two endpoints. A small voltage is produced when the two endpoints are at different temperatures. (For small temperature changes, the voltage is roughly proportional to the temperature difference of the endpoints.)

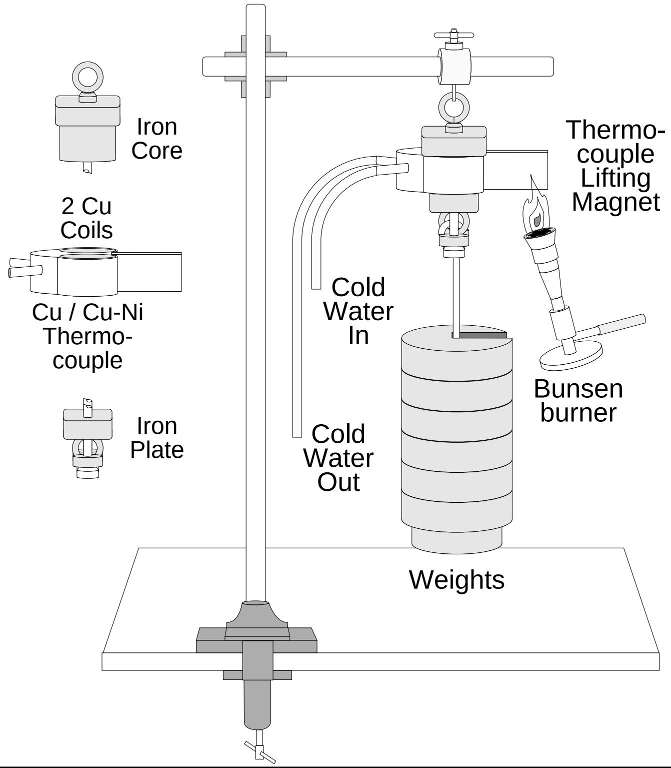
This demo has both a thermocouple made of iron and copper wires, and a thermopile. The thermopile is a device made up of many thermocouples in series so that the voltage produced is much larger than with a single thermocouple. The reflective horn focuses infrared radiation (heat) onto the thermopile.

The iron-copper thermocouple should respond favorably to heat from the fingers, and strongly to the heat of a match. The horn thermopile should respond strongly to the hand at a distance of one foot.



THERMOELECTRICITY. D+70+2

Thermocouple magnet: Flame heating, plus water cooling, holds weight.



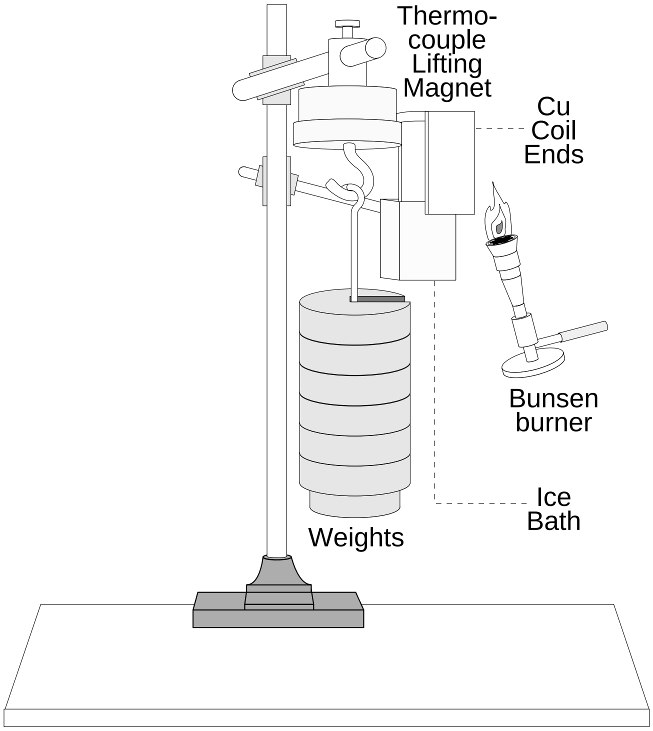
A thermocouple is formed when two dissimilar metals are joined at two endpoints. A small voltage is produced when the two endpoints are at different temperatures.

This thermocouple magnet has just two coils of thick copper (resistance about a millionth of an ohm) and another piece of copper-nickel alloy (placed between the coils). When one end is heated with a bunsen burner, and the other end is cooled with cold flowing water, a voltage is generated on the order of millivolts. The current thus generated in the copper coils is on the order of a hundred amps. The current generates a large magnetic field which is reinforced by the 2 iron cores inserted inside the 2 copper coils.

Under optimal conditions, this thermoelectric magnet is able to support over 200 pounds.

THERMOELECTRICITY. D+70+4

Thermocouple magnet: Flame heating, plus ice bath, holds weight.



A thermocouple is formed when two dissimilar metals are joined at two endpoints. A small voltage is produced when the two endpoints are at different temperatures.

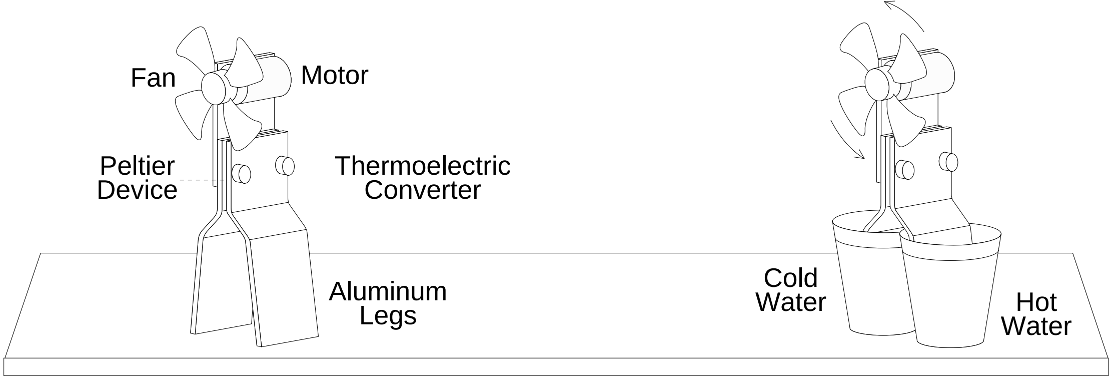
This thermocouple magnet has just one coil of thick copper (resistance abut a millionth of an ohm) and another piece of copper-nickel alloy (placed between the vertical ends of the coil). When one vertical copper end is heated with a bunsen burner, and the other vertical end is cooled in an ice bath, a voltage is generated on the order of millivolts. The current thus generated in the copper coil is on the order of a hundred amps. The current generates a large magnetic field which is reinforced by the iron core inserted inside the copper coil.

Under optimal conditions, this thermoelectric magnet is able to support over 400 pounds.

THERMOELECTRICITY.

D+70+6

Thermoelectric Converter: temperature differential runs fan and motor.



This thermoelectric converter is basically a fan and motor electrically driven by a thermocouple that has one leg in cold water and one leg in hot water. The thermocouple in this demo is actually a Peltier semiconductor device run in reverse. (The Peltier device is usually set up so that a current flowing through the device causes one side to get cold and one side to get hot. In the reverse situation, making one side hot and one side cold causes a current to flow.) See D+70+8 for more info on the Peltier Device.

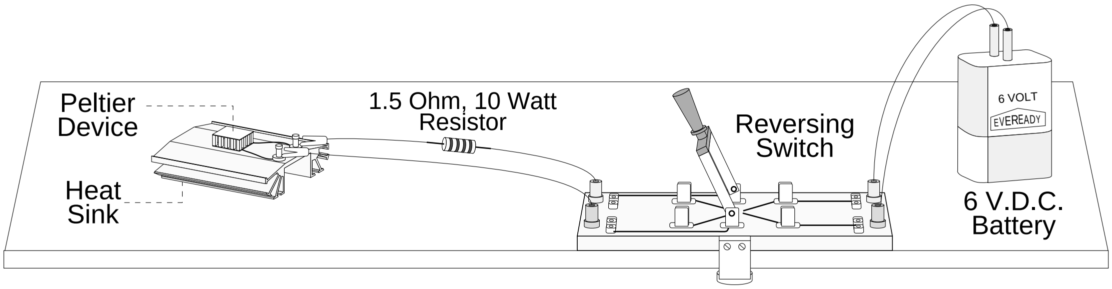
The Peltier device consists of a series of tiny thermoelectric cells made of P and N doped silicon semiconductor material. Heat entering the cell raises the energy level of some of the electrons, freeing them to migrate through the N material. Holes can migrate through the P material. The electrons flow from the N material through the external circuit and drive the fan motor, then recombine with the holes in the P material. As long as there is a sufficient temperature differential (50° C) between the two sides of the cell, the fan turns.

Cold water in the left cup and hot water in the right cup makes the fan rotate counter-clockwise. Hot water in the left cup and cold water in the right cup makes the fan turn clockwise. Boiling water and iced water (or dry ice) give best results.

THERMOELECTRICITY.

D+70+8

Peltier Device: With electric current, thermoelectric heat pump cools or heats.



The Peltier Device is a thermoelectric heat pump. If the switch is thrown so that positive voltage is connected to the red terminal and ground is hooked to the black terminal, the top of the device will get cold, and heat will be radiated out through the heat-sink fins. The device quickly becomes cold enough to freeze a drop of water. If the voltage is reversed (switch is reversed), the water quickly boils.

J.C.A.Peltier discovered in 1834 that when an electric current flows across a junction of two dissimilar conductors, heat is liberated or absorbed at the junction. The direction in which the current flows determines whether heat is liberated or absorbed . This effect depends on the conductors used, and the temperature of the junction. (It is not associated with contact potential or work function, or the shape or dimensions of the materials composing the junction!) Peltier, sending a current through a thermocouple made of antimony and bismuth, froze a drop of water: the first demonstration of thermoelectric refrigeration.

This Peltier Device consists of a series of tiny thermoelectric cells made of P and N doped silicon semiconductor materials. Heat entering the cell raises the energy level of some of the electrons, freeing them to migrate through the N material. Holes can migrate through the P material. This module will produce or absorb 2.9 Watts of power when 2.5 amps flow through it at 2.06 volts. It will exhibit a change in temperature of 67 degrees C at that current.

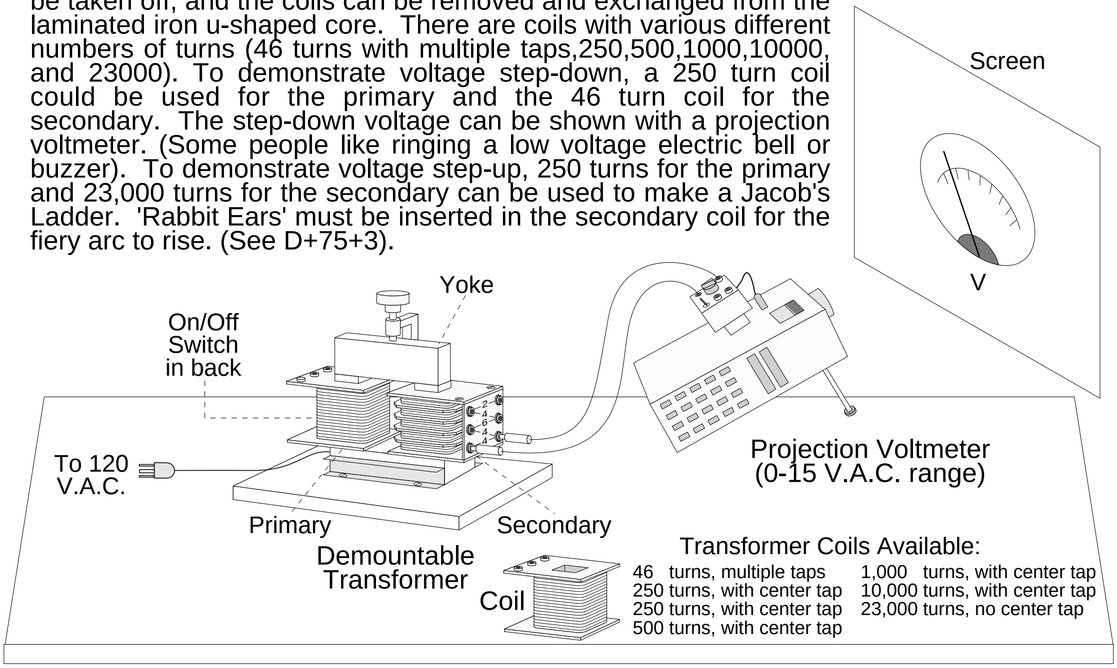
NOTE: Not more than 2.1 amps should flow through the device. If a 6 volt battery is used, then an 1.5 Ohm 10 Watt current-limiting resistor should be in the circuit. A Genencon hand-generator (not shown) can also be used...

TRANSFORMERS.

D+75+0

Demountable transformer with many secondary coils from 10:1 to 1:46.

This is a demonstration transformer apparatus. The iron yoke can be taken off, and the coils can be removed and exchanged from the laminated iron u-shaped core. There are coils with various different numbers of turns (46 turns with multiple taps,250,500,1000,10000, and 23000). To demonstrate voltage step-down, a 250 turn coil could be used for the primary and the 46 turn coil for the secondary. The step-down voltage can be shown with a projection voltmeter. (Some people like ringing a low voltage electric bell or buzzer). To demonstrate voltage step-up, 250 turns for the primary and 23,000 turns for the secondary can be used to make a Jacob's Ladder. 'Rabbit Ears' must be inserted in the secondary coil for the fiery arc to rise. (See D+75+3).



Transformer Coils Available:

46 turns, multiple taps
250 turns, with center tap
250 turns, with center tap
500 turns, with center tap
1,000 turns, with center tap
10,000 turns, with center tap
23,000 turns, no center tap

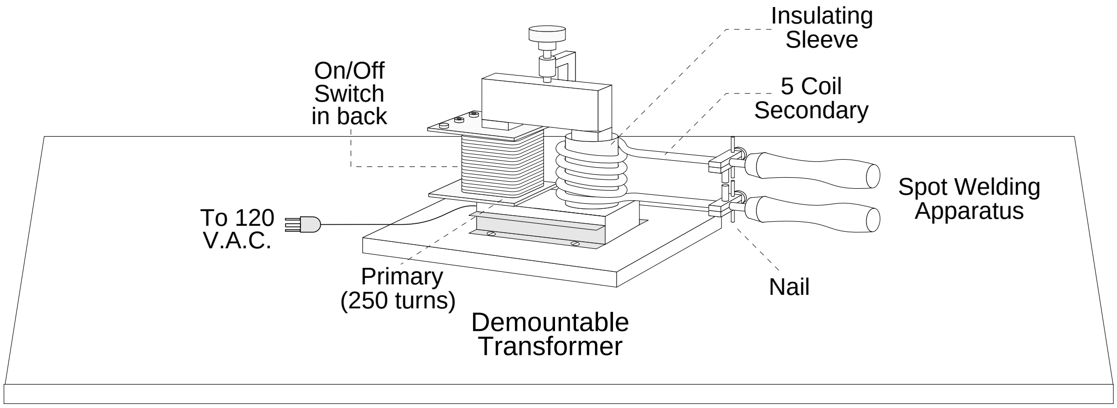
TRANSFORMERS.

D+75+1

Same as D+75+0: Secondary used for spot-welding.

The demonstration transformer shown in D+75+0 can be used to demonstrate spot-welding. The secondary has been replaced with a low-resistance coil of 5 turns (made of bent .8 mm thick copper rod). When the secondary is shorted, several 100 amps can flow. Two nails can be inserted and secured in the welding section. When the handle is squeezed, the nails make contact and glow white hot, and will ultimately fuse. Also, several pieces of thin metal can be overlapped and placed between the welding points. When the handle is squeezed, the metal pieces can be welded together.

Note that there is an insulating sheath separating the secondary coils from the iron core of the transformer. Also, the handles are wood, to minimize shock hazard.

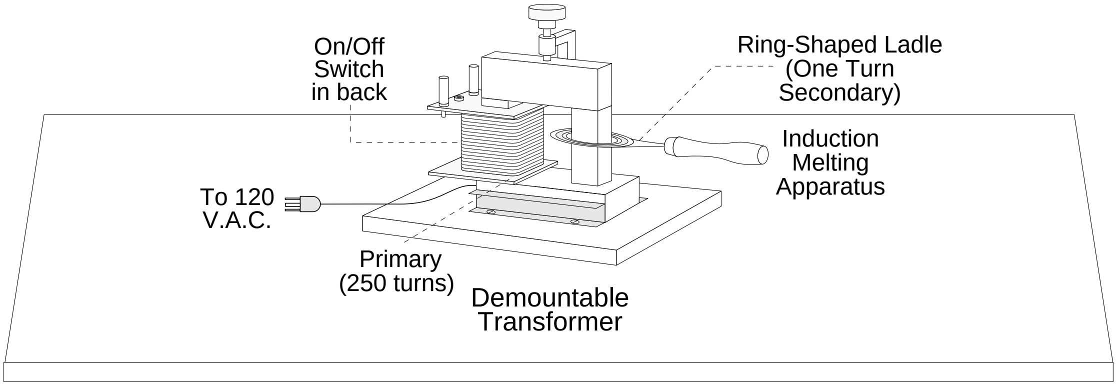


TRANSFORMERS.

D+75+2

Same as D+75+0: Secondary used for induction melting.

The demonstration transformer shown in D+75+0 can be used to demonstrate induction melting. The secondary has been replaced with a low-resistance copper ring (ladle) of 1 turn. The ladle has an annular concavity that is filled with solidified tin. When power is applied to the primary, hundreds of amps flow in the ladle, melting the tin. The handle of the ladle is wood, minimizing shock hazard.

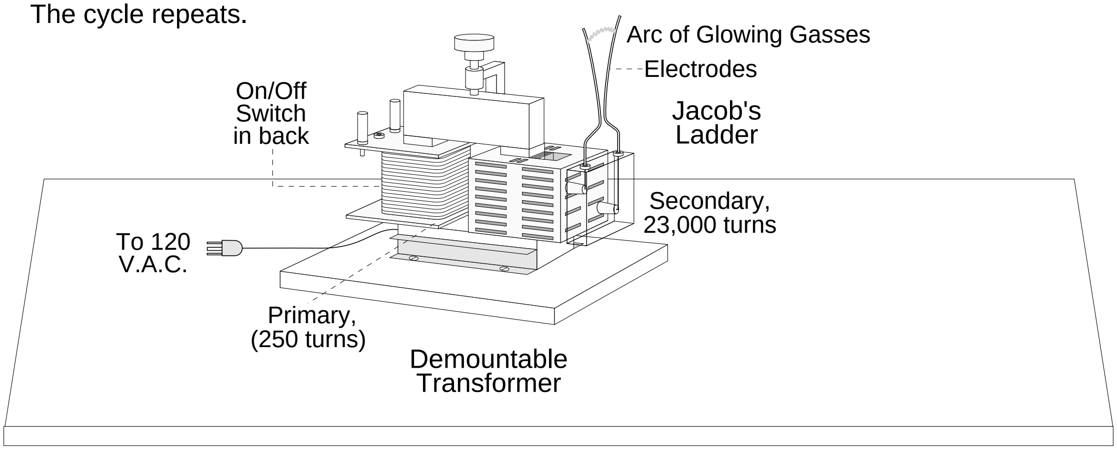


TRANSFORMERS.

D+75+3

Same as D+75+0: Secondary used for small Jacob's Ladder.

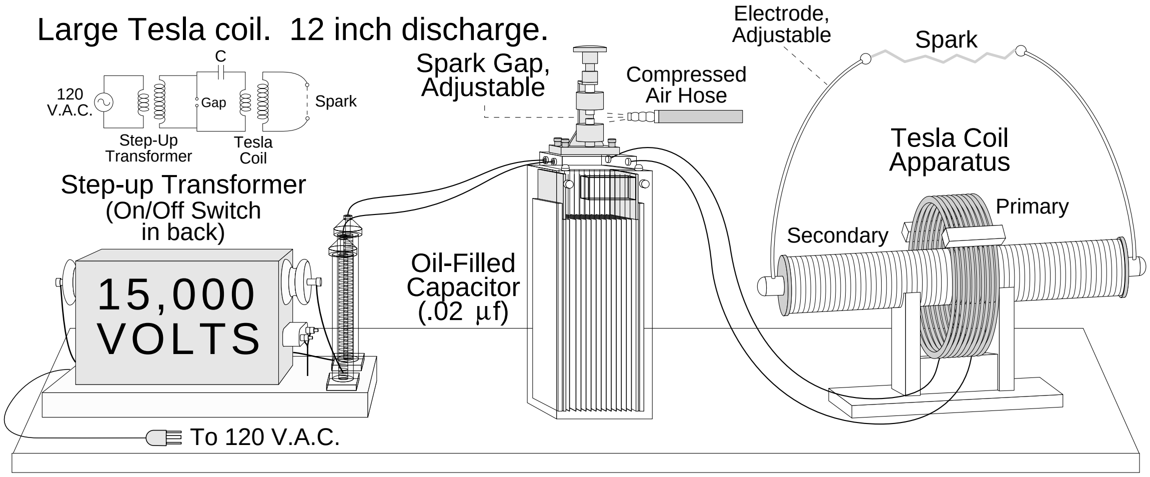
The demonstration transformer shown in D+75+0 can be used to make a small Jacob's Ladder. A 250 turn coil is used for the primary, and a 23,000 turn coil is used for the secondary. When power is applied to the primary, the secondary coil produces about 10,000 volts (maximum current is .02 amps). A voltage this large is capable of ionizing the air between the V-shaped electrodes mounted on the secondary. The electric forces are strongest where the electrodes are closest together, at the base of the V. Thus, a spark jumps from the base of one electrode to the other, creating an arc of heated ionized glowing gases that travels upward. When the glowing arc drifts off the top of the electrodes, the circuit is broken, and the arc renews itself at the base of the electrodes. The cycle repeats.



TRANSFORMERS.

D+75+4

Large Tesla coil. 12 inch discharge.

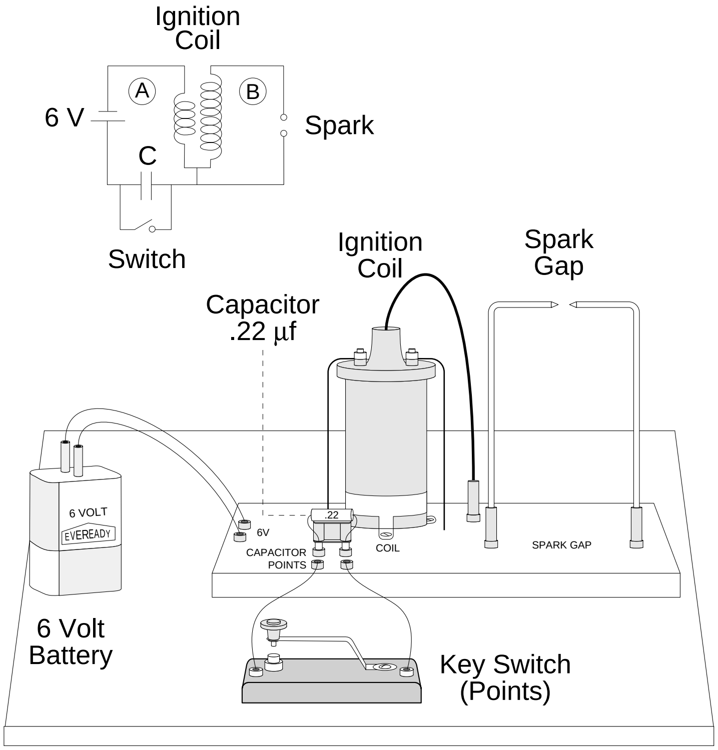


The Tesla Coil is a high frequency, weakly coupled, air-core transformer. Under ideal conditions, this demo is capable of producing 12 inch sparks. The first part of the apparatus is a 120 V.A.C., 60 Hz, step-up transformer that produces about 15,000 V.A.C at the secondary. The leads from the secondary are attached to either side of a spark gap. The spark gap is part of a series tank circuit containing a large, oil-filled capacitor (.02 μf, mica dielectric, rated at 20 kVolts) and the primary coil of the Tesla apparatus (10 turns, 27 μh). If the spark gap is set at about .25 inches, it will take about 2.5 kVolts to break down the air between the gap electrodes (10 kVolts/Inch on average). Thus, when the secondary of the transformer raises to 2.5 kVolts in the A.C. cycle (or lowers to - 2.5 kVolts), a spark will jump across the gap and the tank circuit will ring at its resonant frequency (about 217 kHz). The high frequency is important because the induced voltage in the Tesla secondary is proportional to the frequency of the primary coil signal (and to the square root of the ratio of the secondary winding inductance to the primary winding inductance). A spark of 12 inches means about 120 kV.A.C. NOTE: To tune the Tesla Coil properly, only about 8 turns of the primary are actually used. There are marked spots indicating where to clip the leads. Larger sparks can be produced if compressed air is sprayed through the spark gap, raising the voltage necessary to cause a spark to jump the gap. Also, the gap distance can be increased.

TRANSFORMERS.

D+75+6

Automobile coil makes a spark.

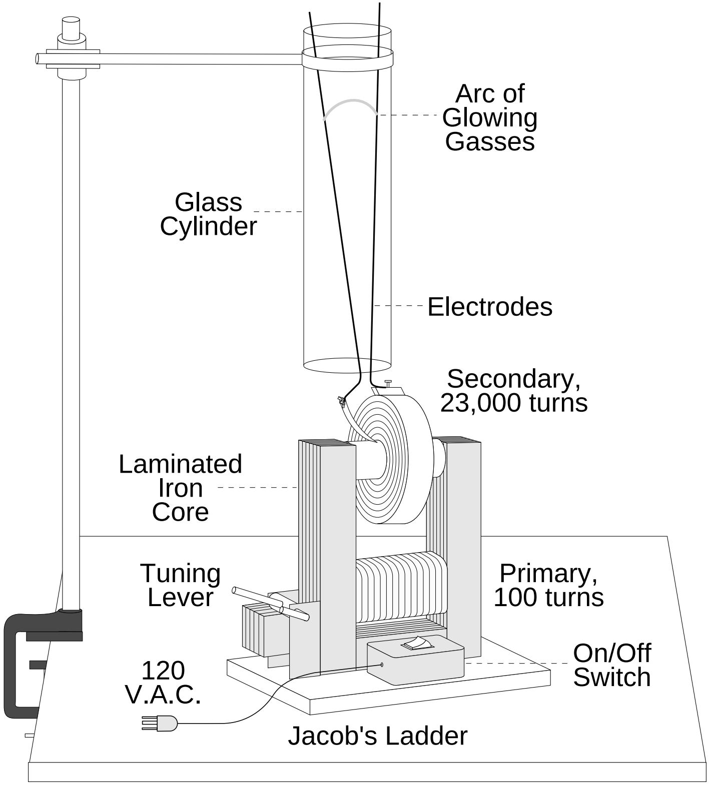


This apparatus demonstrates how an automobile ignition coil generates a high voltage spark. Looking at the circuit diagram, a 6 volt battery is connected in series with the primary of the ignition coil and a capacitor. A switch is connected across the capacitor. When the switch is closed, a constant current flows through circuit 'A', producing a constant magnetic field in the primary coil. Because the field is constant, there is no voltage induced in the ignition coil secondary (circuit 'B'). However, when the switch is released, the energy stored in the primary coil magnetic field is quickly released, and a large voltage (about 5 kVolts) is induced in the secondary coil, producing a spark across the spark gap. (The capacitor is in the circuit mainly to prevent the 'points' of the switch from being damaged by large currents.)

TRANSFORMERS.

D+75+8

Large Jacob's Ladder.



This Jacob's Ladder transformer stands about 3 feet tall. A 100 turn coil is used for the primary, and a 23,000 turn coil is used for the secondary. When 120 V.A.C. power is applied to the primary, the secondary coil produces about 25,000 volts. A voltage this large is capable of ionizing the air between the V-shaped electrodes mounted on top of the apparatus. The electric forces are strongest where the electrodes are closest together, at the base of the V. Thus, a spark jumps from the base of one electrode to the other, creating an arc of heated ionized glowing gases that travels upward. When the glowing arc drifts off the top of the electrodes, the circuit is broken, and the arc renews itself at the base of the electrodes. The cycle repeats.

NOTE: A tuning lever at the base of the apparatus can be used to achieve the optimum arc.

A glass cylinder is used to surround the electrodes to keep the wind currents in the room from extinguishing the arc.

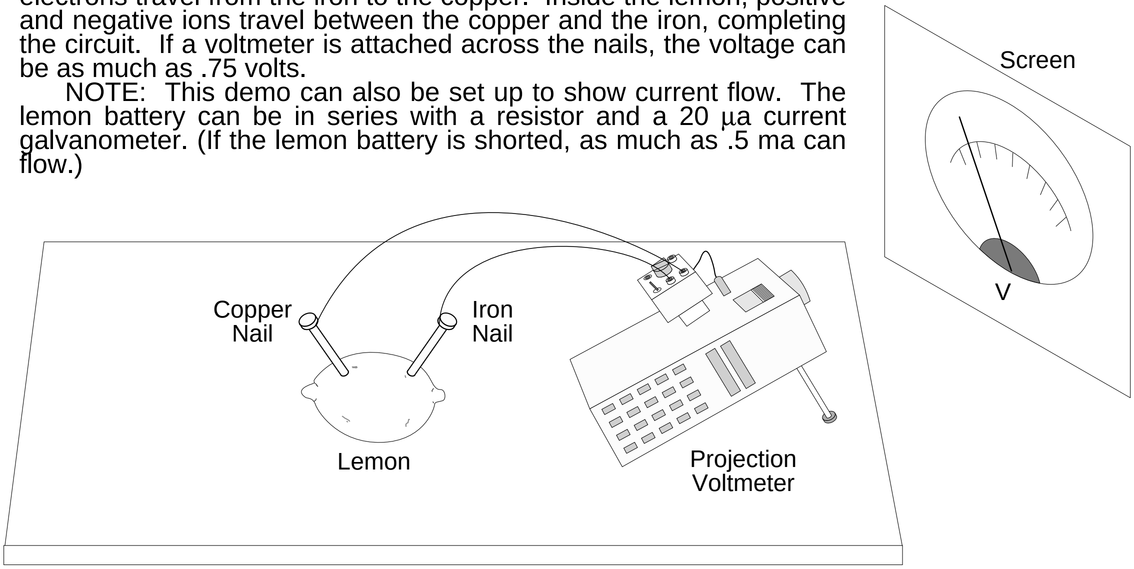
VOLTAIC CELLS.

D+80+0

Copper nail and iron nail in a lemon using a multimeter.

An iron nail and a copper nail are stuck into a medium-sized lemon. The lemon contains water and citric acid. The iron nail is attacked by the acid and tends to slowly dissolve. When an iron molecule goes into solution, it leaves several electrons behind on the iron electrode, charging it negatively. The copper nail has less of a tendency to dissolve, and thus acquires a positive charge with respect to the iron nail. If a wire is attached between the iron nail and the copper nail, electrons travel from the iron to the copper. Inside the lemon, positive and negative ions travel between the copper and the iron, completing the circuit. If a voltmeter is attached across the nails, the voltage can be as much as .75 volts.

NOTE: This demo can also be set up to show current flow. The lemon battery can be in series with a resistor and a 20 µa current galvanometer. (If the lemon battery is shorted, as much as .5 ma can flow.)

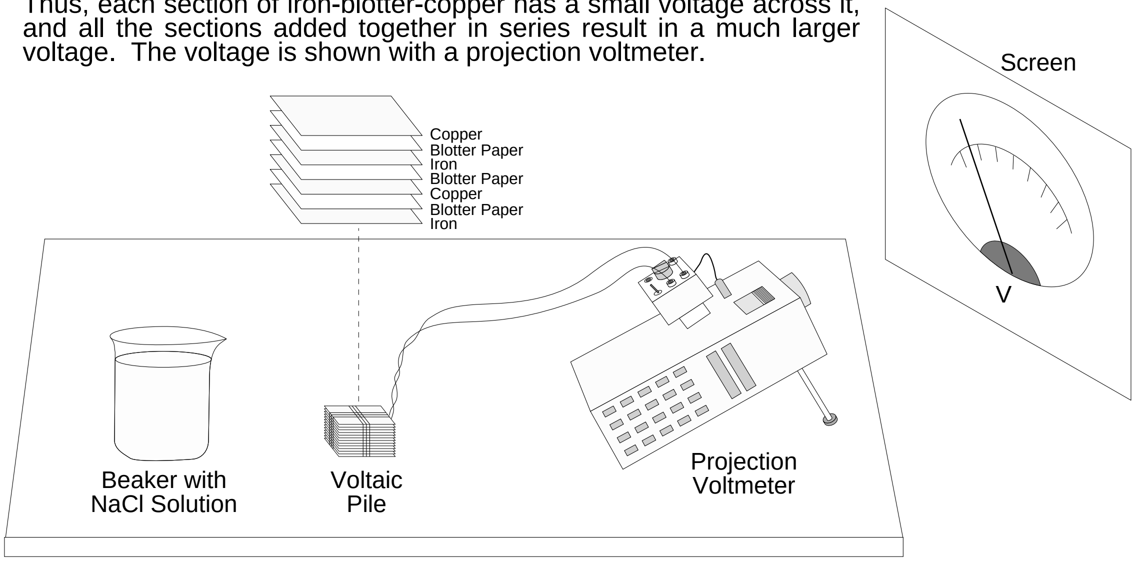


VOLTAIC CELLS. D+80+2

The Voltaic Pile: Alternating metal sheets in NaCl solution.

This voltaic pile is made of alternating layers of iron, blotter paper, and copper plates. When the pile is dipped briefly into the beaker of saline solution, the blotter absorbs and holds the saline solution, and the pile is activated. The pile produces a voltage of about .2 volts.

The saline solution is weakly acidic. The iron plates are attacked by the acid and tend to slowly dissolve, leaving behind negative charges on the iron plates. The copper plates have less tendency to dissolve, and thus acquire a positive charge with respect to the iron. Thus, each section of iron-blotter-copper has a small voltage across it, and all the sections added together in series result in a much larger voltage. The voltage is shown with a projection voltmeter.



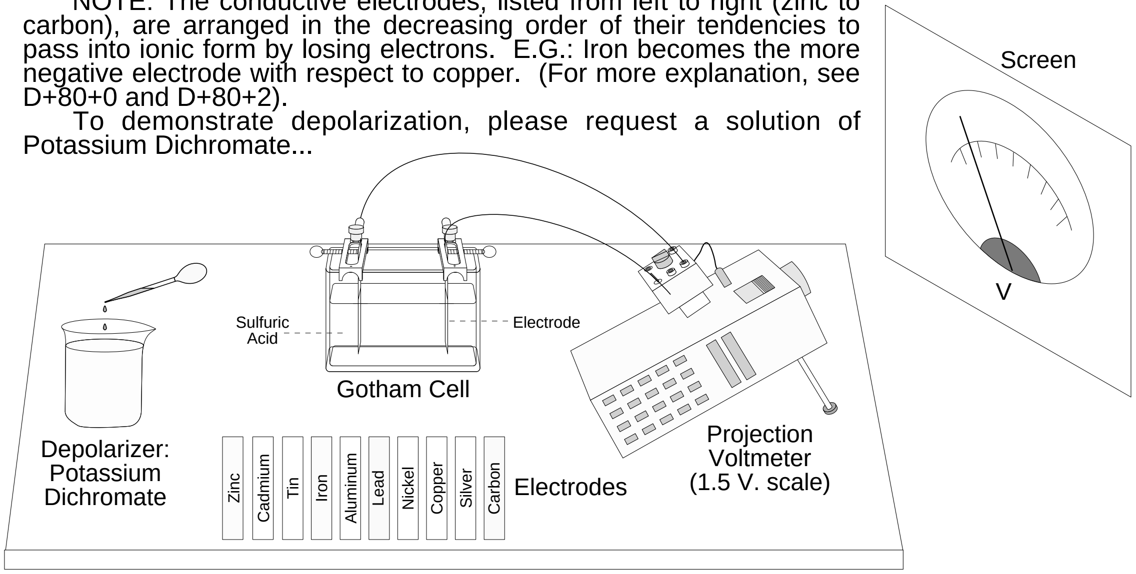
VOLTAIC CELLS. D+80+4

Gotham cell: Assorted metal electrodes in sulfuric acid bath.

The Gotham cell consists of dilute sulfuric acid (6 molar) and 2 electrodes of different conductive materials (zinc, cadmium, tin, iron, aluminum, lead, nickel, copper, silver and carbon). Of the listed electrodes, zinc will be the most negative when inserted in the acid. Carbon will be the most positive. Thus, the cell that will generate the highest voltage will be the zinc-carbon cell, producing about 1.4 volts. All the other combinations of electrodes will yield various smaller voltages.

NOTE: The conductive electrodes, listed from left to right (zinc to carbon), are arranged in the decreasing order of their tendencies to pass into ionic form by losing electrons. E.G.: Iron becomes the more negative electrode with respect to copper. (For more explanation, see D+80+0 and D+80+2).

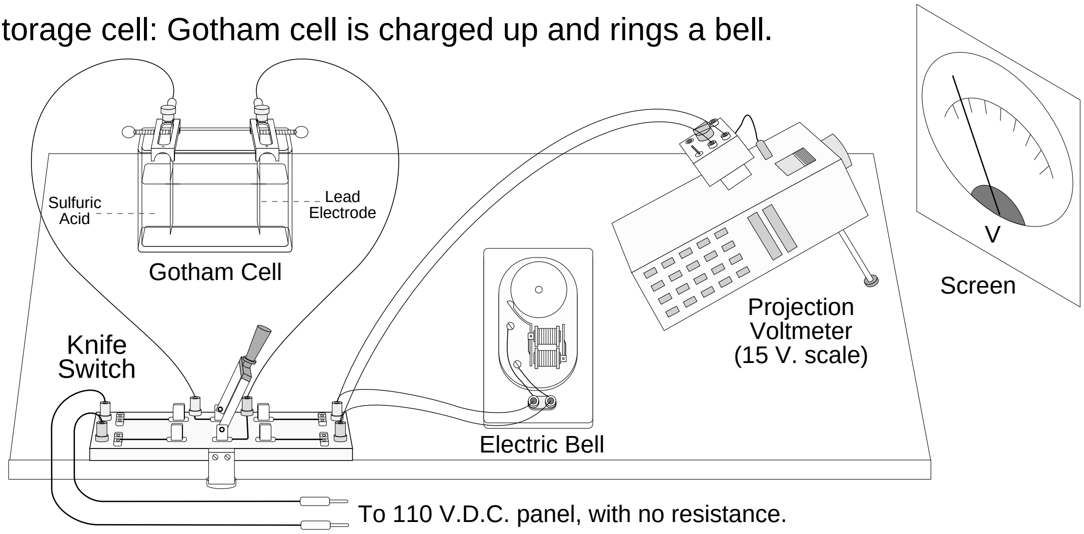
To demonstrate depolarization, please request a solution of Potassium Dichromate...



VOLTAIC CELLS.

D+80+6

Storage cell: Gotham cell is charged up and rings a bell.

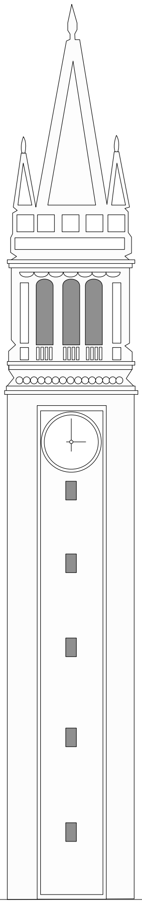


This Gotham cell consists of 2 lead electrodes immersed in dilute sulfuric acid (6 molar). To charge the cell, the knife switch is thrown to the left, and 110 V.D.C. is placed across the lead electrodes for about a minute. Several amps flow through the cell, and the solution bubbles vigorously. When the cell is fully charged (about 2.2 volts), the switch is thrown to the right, and the electric bell rings (drawing about 200 ma).

When the cell is being charged, the negative electrode (cathode) attracts positive hydrogen ions. The charged hydrogen ions are neutralized, and hydrogen gas bubbles out of the solution at the cathode. The positive electrode (anode) attracts the negative SO4 ions, which in turn take hydrogen from water molecules to produce more sulfuric acid. The remaining negative oxygen ions unite chemically with the anode to form a layer of reddish-brown lead oxide.

When the charged cell is placed across the electric bell, the lead dioxide plate becomes the anode. While the cell is discharging, the lead dioxide on the anode is converted into lead sulphate and water. When both electrodes become covered with lead sulphate, no more current flows in the cell. The process is reversible by recharging the cell.

1868



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