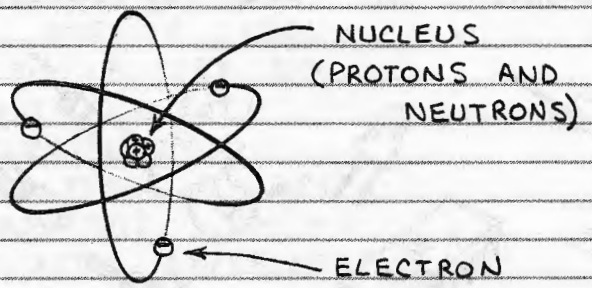
BACK TO BASICS

ELECTRICITY IS AN ESSENTIAL INGREDIENT OF MATTER. THE BEST WAY TO UNDERSTAND THE NATURE OF ELECTRICITY IS TO EXAMINE THE SMALLEST COMPONENT OF EVERY ELEMENT, THE ATOM.

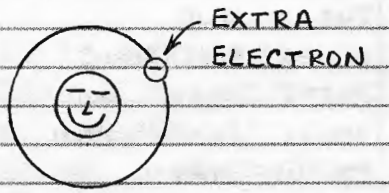


LITHIUM ATOM

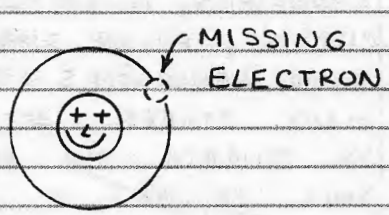
THIS IS A LITHIUM ATOM. THE THIRD SIMPLEST ATOM AFTER HYDROGEN AND HELIUM, LITHIUM ATOMS HAVE 3 ELECTRONS THAT ENCIRCLE A NUCLEUS OF 3 PROTONS AND 4 NEUTRONS.

⊖ ELECTRONS HAVE A NEGATIVE ELECTRICAL CHARGE.
⊕ PROTONS HAVE A POSITIVE ELECTRICAL CHARGE.
○ NEUTRONS HAVE NO ELECTRICAL CHARGE.

☐ IONS — NORMALLY AN ATOM HAS AN EQUAL NUMBER OF ELECTRONS AND PROTONS. THE CHARGES CANCEL TO GIVE THE ATOM NO NET ELECTRICAL CHARGE. IT'S POSSIBLE TO DISLODGE ONE OR MORE ELECTRONS FROM MOST ATOMS. THIS CAUSES THE ATOM TO HAVE A NET POSITIVE CHARGE. IT'S THEN CALLED A POSITIVE ION. IF A STRAY ELECTRON COMBINES WITH A NORMAL ATOM, THE ATOM HAS A NET NEGATIVE CHARGE AND IS CALLED A NEGATIVE ION.

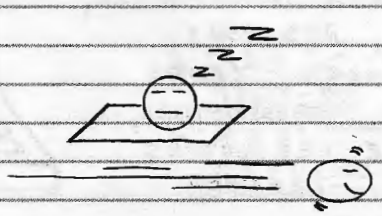


NEGATIVE ION

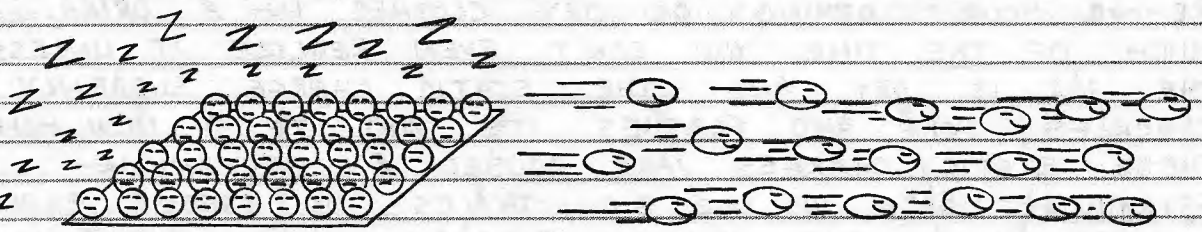


POSITIVE ION

☐ ELECTRONS — FREE ELECTRONS CAN MOVE AT HIGH SPEED THROUGH METALS, GASES AND A VACUUM. OR THEY CAN REST ON A SURFACE.



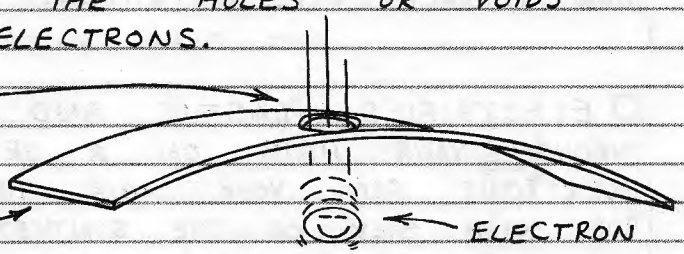
☐ MORE ABOUT FREE ELECTRONS — MANY TRILLIONS OF ELECTRONS CAN REST ON A SURFACE OR TRAVEL THROUGH SPACE OR MATTER AT NEAR THE SPEED OF LIGHT (186,000 MILES PER SECOND)!



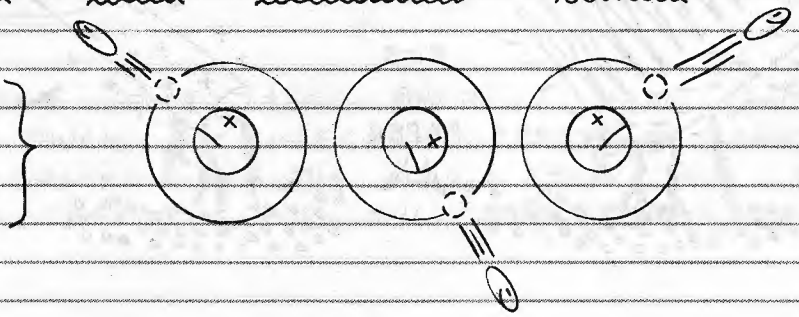
RESTING ELECTRONS MOVING ELECTRONS

☐ RESTING ELECTRONS — A GROUP OF NEGATIVE ELECTRONS ON A SURFACE CAUSES THE SUREACE TO BE NEGATIVELY CHARGED. SINCE THE ELECTRONS ARE NOT MOVING, THE SURFACE CAN BE SAID TO HAVE A NEGATIVE STATIC ELECTRICAL CHARGE.

☐ MOVING ELECTRONS — A STREAM OF MOVING ELECTRONS IS CALLED AN ELECTRICAL CURRENT. RESTING ELECTRONS CAN QUICKLY FORM AN ELECTRICAL CURRENT IF PLACED NEAR A CLUSTER OF POSITIVE IONS. THE POSITIVELY CHARGED IONS WILL ATTRACT THE ELECTRONS WHICH WILL RUSH IN TO FILL THE "HOLES" OR VOIDS LEFT BY THE MISSING ELECTRONS.



☐ MISSING ELECTRONS — MECHANICAL FRICTION, LIGHT, HEAT OR A CHEMICAL REACTION MAY REMOVE ELECTRONS FROM A SURFACE. THIS CAUSES THE SURFACE TO BE POSITIVELY CHARGED. SINCE THE POSITIVELY CHARGED ATOMS ARE AT REST, THE SURFACE CAN BE SAID TO HAVE A POSITIVE STATIC ELECTRICAL CHARGE.



DIRECT CURRENT ELECTRICITY

AN ELECTRICAL CURRENT CAN FLOW IN EITHER OF TWO DIRECTIONS THROUGH A CONDUCTOR. IF IT FLOWS IN ONLY ONE DIRECTION, WHETHER STEADILY OR IN PULSES, IT'S CALLED DIRECT CURRENT (DC). IT'S IMPORTANT TO BE ABLE TO SPECIFY THE QUANTITY AND POWER OF A DIRECT CURRENT. HERE ARE THE KEY TERMS:

☐ CURRENT (I) — CURRENT IS THE QUANTITY OF ELECTRONS PASSING A GIVEN POINT. THE UNIT OF CURRENT IS THE AMPERE. ONE AMPERE IS 6,280,000,000,000,000,000 (6.28×10^{18}) ELECTRONS PASSING A POINT IN ONE SECOND.

☐ VOLTAGE (V OR E) — VOLTAGE IS ELECTRICAL PRESSURE OR FORCE. VOLTAGE IS SOMETIMES REFERRED TO AS POTENTIAL. VOLTAGE DROP IS THE DIFFERENCE IN VOLTAGE BETWEEN THE TWO ENDS OF A CONDUCTOR THROUGH WHICH CURRENT IS FLOWING. IF WE COMPARE CURRENT TO WATER FLOWING THROUGH A PIPE, THEN VOLTAGE IS THE WATER PRESSURE.

☐ POWER (P) — THE WORK PERFORMED BY AN ELECTRICAL CURRENT IS CALLED POWER. THE UNIT OF POWER IS THE WATT. THE POWER OF A DIRECT CURRENT IS ITS VOLTAGE TIMES ITS CURRENT.

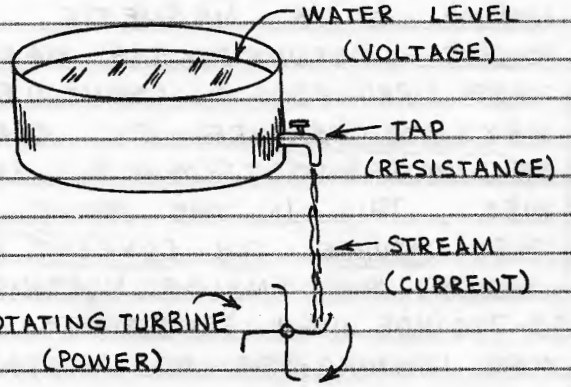
☐ RESISTANCE (R) — CONDUCTORS ARE NOT PERFECT. THEY RESIST TO SOME DEGREE THE FLOW OF CURRENT. THE UNIT OF RESISTANCE IS THE OHM (Ω). A POTENTIAL DIFFERENCE OF ONE VOLT WILL FORCE A CURRENT OF ONE AMPERE THROUGH A RESISTANCE OF ONE OHM. THE RESISTANCE OF A CONDUCTOR IS ITS VOLTAGE DROP DIVIDED BY THE CURRENT FLOWING THROUGH THE CONDUCTOR.

☐ MR. OHM'S LAW — GIVEN ANY TWO OF THE ABOVE, YOU CAN FIND THE OTHER TWO USING THESE FORMULAS KNOWN AS OHM'S LAW:

$$V = I \times R$$
$$I = V / R$$
$$R = V / I$$
$$P = V \times I \text{ (OR) } I^2 \times R$$

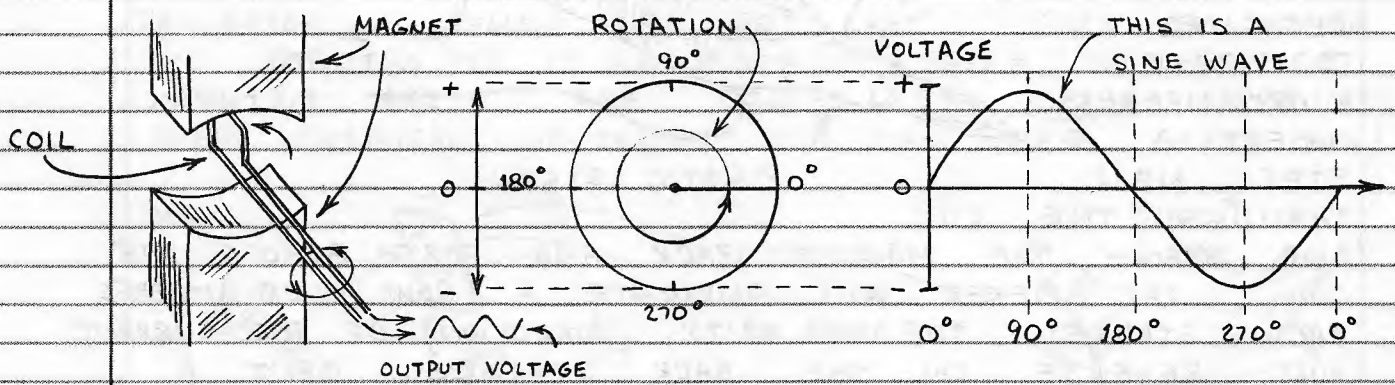
WE'LL REFER TO OHM'S LAW LATER IN THIS BOOK...

☐ SUMMING UP — THIS IS THE "WATER ANALOGY":



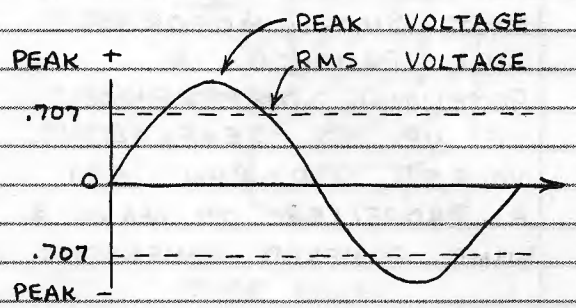
ALTERNATING CURRENT ELECTRICITY

LOOK BACK AT THE HOMEMADE COIL AND MAGNET "GENERATOR" ON THE PRECEEDING PAGE. WHEN THE MAGNET IS STROKED IN ONE DIRECTION ALONG THE COIL, ELECTRONS IN THE WIRE ARE MOVED IN ONE DIRECTION AND A DIRECT CURRENT IS PRODUCED. ON THE BACK STROKE, UNLESS THE MAGNET IS MOVED AWAY FROM THE COIL, THE DIRECTION OF CURRENT FLOW IS REVERSED. THEREFORE, IF THE MAGNET IS STROKED BACK AND FORTH ALONG THE COIL, A CURRENT WHICH ALTERNATES IN DIRECTION OR POLARITY IS PRODUCED. IT'S CALLED AN ALTERNATING CURRENT. ALTERNATING CURRENT (AC) IS USUALLY PRODUCED BY ROTATING A COIL IN A MAGNETIC FIELD.



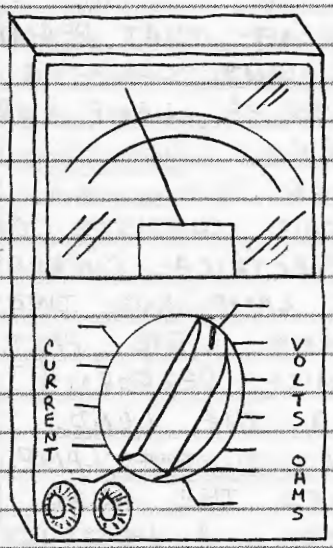
ROTATING COIL — VOLTAGE OUTPUT — AC SINE WAVE

☐ SINE WAVE MEASUREMENT — AC VOLTAGE IS USUALLY SPECIFIED AT A VALUE EQUAL TO THE DC VOLTAGE CAPABLE OF DOING THE SAME WORK. FOR A SINE WAVE THIS VALUE IS 0.707 TIMES THE PEAK VOLTAGE. IT'S CALLED THE RMS (ROOT-MEAN-SQUARE) VOLTAGE. THE PEAK VOLTAGE (OR CURRENT) IS 1.41 TIMES THE RMS VALUE. HOUSEHOLD LINE VOLTAGE IS SPECIFIED ACCORDING TO ITS RMS VALUE. THEREFORE, A HOUSEHOLD VOLTAGE OF 120-VOLTS CORRESPONDS TO A PEAK VOLTAGE OF 120 x 1.41 OR 169.2-VOLTS.

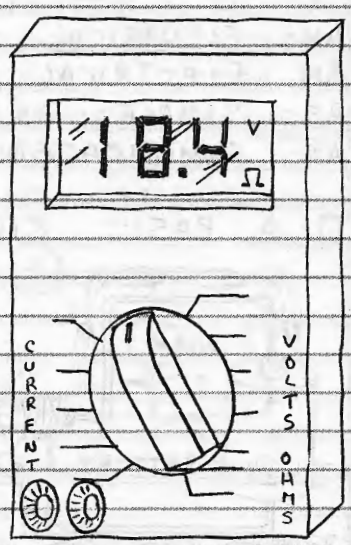


☐ WHY AC IS USED — AC IS BETTER SUITED THAN DC FOR TRANSMISSION THROUGH LONG DISTANCE POWER LINES. A WIRE CARRYING AC WILL INDUCE A CURRENT IN A NEARBY WIRE. THIS IS THE PRINCIPLE BEHIND THE TRANSFORMER.

MEASURING AC AND DC



YOU CAN EASILY MEASURE AC AND DC VOLTAGE AND CURRENT WITH AN INSTRUMENT CALLED THE MULTIMETER. ANALOG MULTIMETERS USE A MOVING COIL METER. DIGITAL MULTIMETERS HAVE A DIGITAL READOUT. THE MULTIMETER IS THE SINGLE MOST IMPORTANT ELECTRONIC TEST INSTRUMENT.



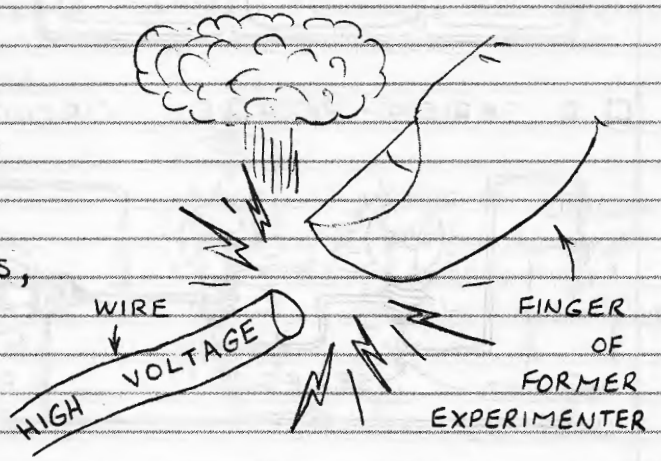
☐ ANALOG MULTIMETER — LESS EXPENSIVE, SOMEWHAT LESS PRECISE THAN DIGITAL TYPES. BEST BY FAR FOR OBSERVING THE TREND OF A SLOWLY CHANGING VOLTAGE, CURRENT OR RESISTANCE.

☐ DIGITAL MULTIMETER — HIGHLY ACCURATE AND EASIER TO READ THAN ANALOG TYPES. BEST FOR FINDING THE PRECISE VALUE OF A VOLTAGE, CURRENT OR RESISTANCE.

☐ SUMMING UP MULTIMETERS — THEY'RE INDISPENSABLE! EVEN IF YOU HAVE ONLY A PASSING INTEREST YOU SHOULD CONSIDER BUYING ONE BECAUSE IT HAS MANY USES IN THE HOME, ON THE JOB AND WHEN WORKING WITH APPLIANCES AND MOTOR VEHICLES. IF YOU'RE SERIOUS ABOUT ELECTRONICS, CONSIDER BUYING A QUALITY HIGH-IMPEDANCE MULTIMETER THAT WILL HAVE LITTLE OR NO EFFECT ON THE DEVICE OR CIRCUIT YOU'RE MEASURING. IDEALLY, YOU SHOULD HAVE BOTH THE ANALOG AND DIGITAL TYPES.

ELECTRICAL SAFETY

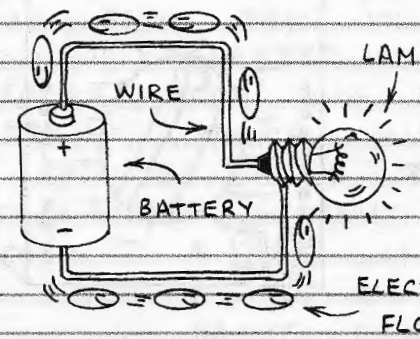
ELECTRICITY CAN KILL! IF YOU WANT TO BE AROUND LONG ENOUGH TO ENJOY EXPERIMENTING WITH ELECTRONICS, ALWAYS TREAT ELECTRICITY WITH THE RESPECT IT DESERVES. WE'LL LOOK AT SAFETY AGAIN LATER.



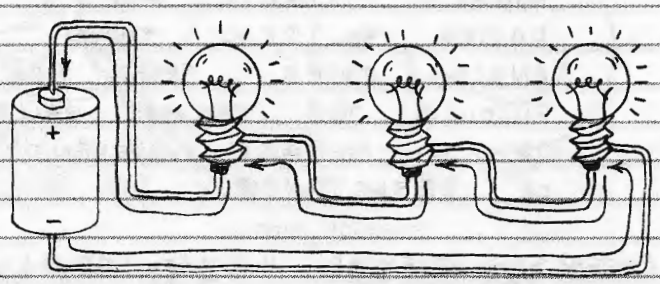
ELECTRICAL CIRCUITS

AN ELECTRICAL CIRCUIT IS ANY ARRANGEMENT THAT PERMITS AN ELECTRICAL CURRENT TO FLOW. A CIRCUIT CAN BE AS SIMPLE AS A BATTERY CONNECTED TO A LAMP OR AS COMPLICATED AS A DIGITAL COMPUTER.

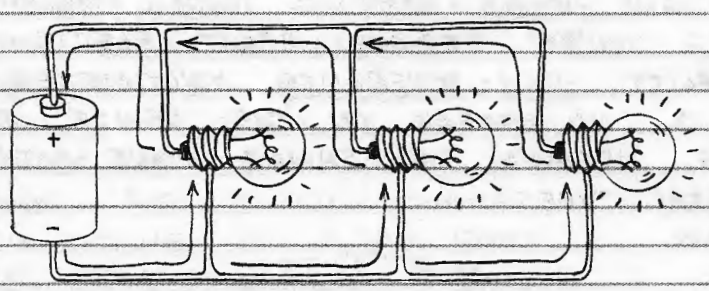
☐ A BASIC CIRCUIT — THIS BASIC CIRCUIT CONSISTS OF A SOURCE OF ELECTRICAL CURRENT (A BATTERY), A LAMP AND TWO CONNECTION WIRES. THE PART OF A CIRCUIT WHICH PERFORMS WORK IS CALLED THE LOAD. HERE THE LOAD IS THE LAMP. IN OTHER CIRCUITS THE LOAD CAN BE A MOTOR, A HEATING ELEMENT, AN ELECTROMAGNET, ETC.



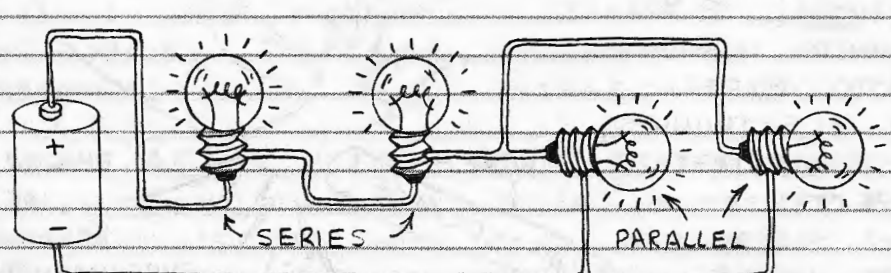
☐ A SERIES CIRCUIT — A CIRCUIT MAY INCLUDE MORE THAN ONE COMPONENT (SWITCH, LAMP, MOTOR, ETC.). A SERIES CIRCUIT IS FORMED WHEN CURRENT FLOWING THROUGH ONE COMPONENT FIRST FLOWS THROUGH ANOTHER. (ARROWS SHOW DIRECTION OF ELECTRON FLOW.)



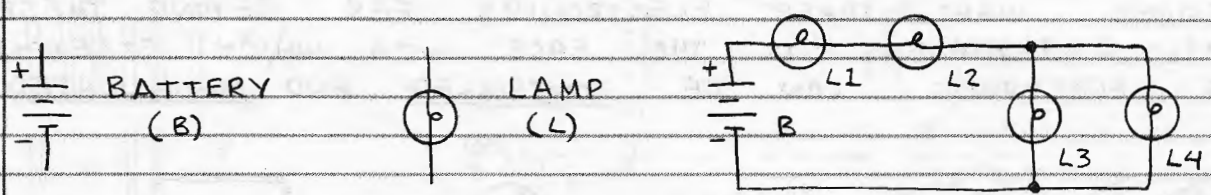
☐ A PARALLEL CIRCUIT — A PARALLEL CIRCUIT IS FORMED WHEN TWO OR MORE COMPONENTS ARE CONNECTED SO CURRENT CAN FLOW THROUGH ONE COMPONENT WITHOUT HAVING FIRST TO FLOW THROUGH ANOTHER.



☐ A SERIES-PARALLEL CIRCUIT — MANY ELECTRICAL CIRCUITS ARE BOTH SERIES AND PARALLEL. ALL PROVIDE A COMPLETE PATH BETWEEN THE CIRCUIT AND ITS POWER SUPPLY.



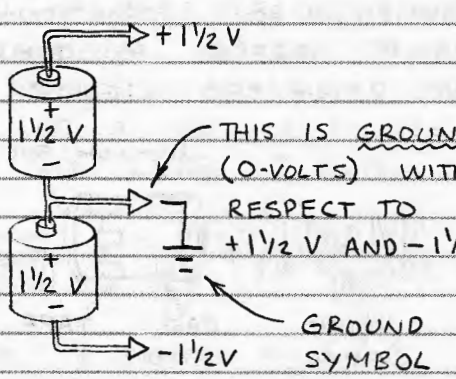
☐ CIRCUIT DIAGRAMS — THUS FAR THE ELECTRICAL CIRCUITS SHOWN IN THIS BOOK HAVE BEEN ILLUSTRATED IN PICTORIAL FORM. PICTORIAL VERSIONS OF CIRCUITS WILL BE USED IN THE NEXT SEVERAL CHAPTERS AS WELL. LATER IN THE BOOK THE PICTORIALS WILL BE REPLACED BY CIRCUIT DIAGRAMS. IN A CIRCUIT DIAGRAM PICTORIAL VIEWS OF COMPONENTS ARE REPLACED BY COMPONENT SYMBOLS.



COMPONENT SYMBOLS — SERIES-PARALLEL CIRCUIT

☐ ELECTRICAL "SHORT" CIRCUIT — WHEN A WIRE OR OTHER CONDUCTOR IS PLACED ACROSS THE CONNECTIONS OF A COMPONENT, SOME OR ALL OF ANY CURRENT IN THE CIRCUIT MAY TAKE A SHORTCUT THROUGH THE CONDUCTOR. "SHORT" CIRCUITS SUCH AS THIS ARE USUALLY UNDESIRABLE AT BEST. THEY CAN CAUSE BATTERIES TO RAPIDLY LOSE THEIR CAPACITY. AND THEY CAN CAUSE DAMAGE TO WIRING AND COMPONENTS. "SHORT" CIRCUITS CAN EVEN CAUSE ENOUGH HEAT TO IGNITE THE INSULATION ON A WIRE! CAUTION: THE HUMAN BODY CONDUCTS ELECTRICITY. THEREFORE CARELESSLY TOUCHING AN ELECTRICAL CIRCUIT MAY CAUSE A "SHORT" CIRCUIT. IF THE VOLTAGE AND CURRENT ARE HIGH ENOUGH, YOU MAY RECEIVE A DANGEROUS OR EVEN LETHAL SHOCK.

☐ ELECTRICAL "GROUND" — ONE OF THE WIRES OF THE AC LINE IS CONNECTED TO EARTH BY A METAL ROD. METAL ENCLOSURES OF ELECTRICALLY POWERED DEVICES ARE CONNECTED TO THIS GROUND WIRE. THIS PREVENTS A SHOCK HAZARD SHOULD A NON-GROUNDED WIRE MAKE CONTACT WITH THE METAL ENCLOSURE. WITHOUT THE GROUND CONNECTION, A PERSON TOUCHING THE DEVICE WHILE STANDING ON THE GROUND OR A WET FLOOR MIGHT RECEIVE A DANGEROUS SHOCK. GROUND ALSO REFERS TO THE POINT IN A CIRCUIT AT ZERO VOLTAGE, WHETHER OR NOT IT'S CONNECTED TO GROUND. FOR INSTANCE, THE MINUS (-) SIDE OF THE BATTERY IN THE CIRCUITS ABOVE AND ON THE PRECEEDING PAGE CAN BE CONSIDERED GROUND.

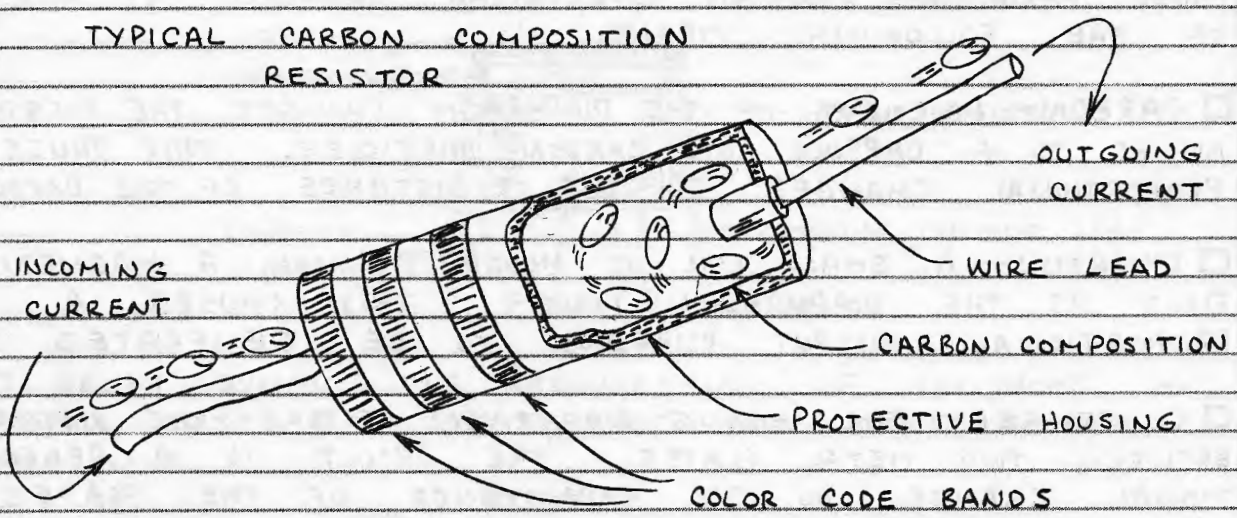


RESISTORS

RESISTORS COME IN DOZENS OF SIZES AND SHAPES BUT THEY ALL DO THE SAME THING: LIMIT* CURRENT. MORE ABOUT THAT LATER. FIRST, LET'S SEE HOW A TYPICAL RESISTOR IS MADE:

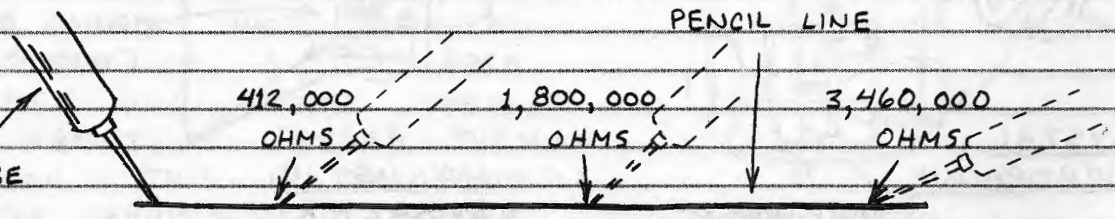
*OR RESIST

TYPICAL CARBON COMPOSITION RESISTOR

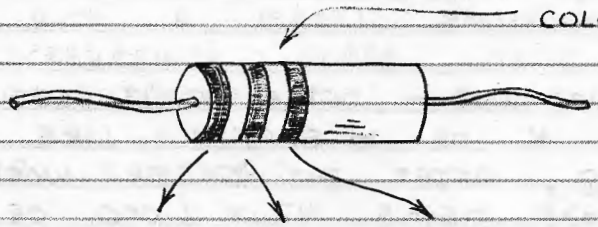


"CARBON COMPOSITION" IS JUST A FANCY WAY OF DESCRIBING POWDERED CARBON MIXED WITH A GLUE-LIKE BINDER. THIS KIND OF RESISTOR IS EASY TO MAKE. AND ITS RESISTANCE CAN BE CHANGED FROM ONE RESISTOR TO THE NEXT SIMPLY BY CHANGING THE RATIO OF CARBON PARTICLES TO BINDER. MORE CARBON GIVES LESS RESISTANCE.

☐ DO-IT-YOURSELF RESISTORS — YOU CAN MAKE A RESISTOR BY DRAWING A LINE WITH A SOFT LEAD PENCIL ON A SHEET OF PAPER. MEASURE THE RESISTANCE OF THE LINE OR POINTS ALONG IT BY TOUCHING THE PROBES OF A MULTIMETER TO THE LINE. BE SURE TO SET THE MULTIMETER TO ITS HIGHEST RESISTANCE SCALE. THE RESISTANCE OF A SINGLE LINE MAY BE TOO HIGH TO MEASURE. IF SO, DRAW OVER THE LINE A DOZEN OR SO TIMES. HERE'S WHAT I MEASURED:



☐ RESISTOR COLOR CODE — SEE THOSE COLOR CODE BANDS ON THE RESISTOR PICTORIAL? IN REAL LIFE THEY'RE KIND OF PRETTY. BUT THEY HAVE A FAR MORE IMPORTANT PURPOSE: THEY INDICATE THE RESISTANCE OF THE RESISTOR THEY DECORATE. HERE'S HOW:



COLOR	1	2	3 (MULTIPLIER)
BLACK	0	0	1
BROWN	1	1	10
RED	2	2	100
ORANGE	3	3	1,000
YELLOW	4	4	10,000
GREEN	5	5	100,000
BLUE	6	6	1,000,000
VIOLET	7	7	10,000,000
GRAY	8	8	100,000,000
WHITE	9	9	(NONE)

NOTE: SOMETIMES THERE'S A FOURTH BAND. IT INDICATES THE TOLERANCE* OF THE RESISTOR:

GOLD = ±5%
SILVER = ±10%
NONE = ±20%

* OR ACCURACY

LOOKS COMPLICATED THE FIRST TIME... BUT YOU'LL QUICKLY LEARN HOW TO USE IT. FOR EXAMPLE, WHAT'S THE RESISTANCE OF A RESISTOR COLOR CODED YELLOW, VIOLET AND RED? YELLOW IS THE FIRST COLOR SO THE FIRST NUMBER IS 4. VIOLET IS THE SECOND COLOR SO THE SECOND NUMBER IS 7. SINCE THE THIRD COLOR IS RED, THE MULTIPLIER IS 100. THEREFORE, THE RESISTANCE IS 47 x 100 OR 4700 OHMS. NO FOURTH COLOR BAND MEANS THE ACTUAL RESISTANCE IS 4700 ±20%. 20% OF 4700 IS 940. THEREFORE, THE ACTUAL VALUE IS BETWEEN 3760 AND 5640 OHMS.

☐ SUBSTITUTING RESISTORS — WHAT IF YOU NEED A 6700-OHM RESISTOR BUT CAN ONLY FIND A 6800-OHM UNIT? YOU CAN ALMOST ALWAYS USE ANY VALUE WITHIN 10 OR 20% OF THE REQUIRED VALUE SO GO AHEAD AND USE IT. IF A PARTICULAR CIRCUIT REQUIRES MORE ACCURACY IT WILL TELL YOU. OF COURSE YOU CAN BUILD UP CUSTOM RESISTANCES BY CONNECTING TWO OR MORE RESISTORS IN SERIES OR IN PARALLEL. MORE ABOUT THAT LATER.

☐ RESISTOR SUBSTITUTION PRECAUTIONS — RESISTORS THAT CONDUCT LOTS OF CURRENT CAN BECOME VERY HOT! THEREFORE, ALWAYS USE RESISTORS HAVING THE PROPER POWER RATING. IF A PROJECT YOU'RE BUILDING DOESN'T SPECIFY THE POWER RATING FOR ITS RESISTORS, IT'S USUALLY OK TO USE ¼ OR ½ WATT UNITS.

☐ SOME RESISTOR SHORTHAND — OFTEN YOU'LL SEE RESISTORS DESIGNATED WITH A K OR M SUFFIX. LIKE 47K OR 10M. K MEANS KILO, AFTER THE GREEK WORD FOR 1,000. THEREFORE, 47K MEANS 47 × 1,000 OR 47,000. M IS SHORT FOR MEGOHM OR 1,000,000 OHMS. THEREFORE A 1M RESISTOR HAS A RESISTANCE OF 1 × 1,000,000 OR 1,000,000 OHMS. SUMMING UP...

K = × 1,000 (47K = 47 × 1,000 = 47,000 OHMS)

M = × 1,000,000 (2.2M = 2.2 × 1,000,000 = 2,200,000 OHMS)

☐ OTHER KINDS OF RESISTORS — THE CARBON COMPOSITION RESISTOR IS ONLY ONE OF SEVERAL MAJOR KINDS OF RESISTORS. HERE ARE OTHERS:

METAL FILM RESISTORS. VARIOUS KINDS OF RESISTORS THAT USE A THIN FILM OF METAL OR A METAL PARTICLE MIXTURE TO ACHIEVE VARIOUS RESISTANCES.

CARBON FILM RESISTORS. THESE ARE MADE BY DEPOSITING A CARBON FILM ON A SMALL CERAMIC CYLINDER. A SPIRAL GROOVE CUT INTO THE FILM CONTROLS THE LENGTH OF CARBON BETWEEN THE LEADS, HENCE THE RESISTANCE.

WIRE-WOUND RESISTORS. THESE CONSIST OF A TUBULAR FORM WRAPPED WITH COILS OF RESISTANCE WIRE. THEY ARE VERY ACCURATE AND CAN TAKE LOTS OF HEAT.

PHOTORESISTORS. ALSO CALLED PHOTOCELLS. MADE FROM A LIGHT SENSITIVE MATERIAL LIKE CADMIUM SULFIDE. INCREASING THE LIGHT LEVEL DECREASES THE RESISTANCE. MORE ABOUT THIS LATER.

THERMISTORS. THIS IS A TEMPERATURE SENSITIVE RESISTOR. INCREASING THE TEMPERATURE DECREASES THE RESISTANCE (IN MOST CASES).

☐ VARIABLE RESISTORS — OFTEN IT'S NECESSARY TO CHANGE THE RESISTANCE OF A RESISTOR. VARIABLE RESISTORS ARE CALLED POTENTIOMETERS. THEY ARE USED TO ALTER THE VOLUME OF A RADIO, CHANGE THE BRIGHTNESS OF A LAMP, ADJUST THE CALIBRATION OF A METER, ETC. TRIMMERS ARE POTENTIOMETERS EQUIPPED WITH A PLASTIC THUMBWHEEL OR A SLOT FOR A SCREWDRIVER BLADE. THEY ARE DESIGNED FOR OCCASIONAL ADJUSTMENT.

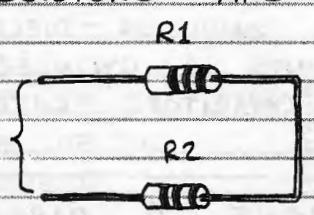
☐ RESISTOR SYMBOLS:

FIXED RESISTOR POTENTIOMETER THERMISTOR PHOTORESISTOR

HOW RESISTORS ARE USED

☐ SERIES CIRCUIT — OFTEN RESISTORS ARE CONNECTED IN SERIES LIKE THIS:

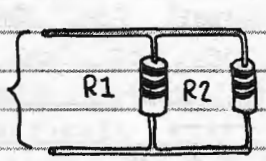
THE TOTAL RESISTANCE IS SIMPLY THE SUM OF THE INDIVIDUAL RESISTANCES.



$$R_T = R1 + R2$$

☐ PARALLEL CIRCUIT — RESISTORS CAN ALSO BE CONNECTED IN PARALLEL LIKE THIS:

THE TOTAL RESISTANCE IS THE PRODUCT OF THE TWO RESISTANCES DIVIDED BY THEIR SUM.



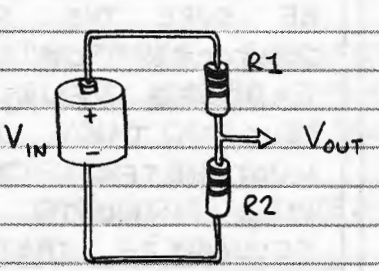
$$R_T = \frac{R1 \times R2}{R1 + R2}$$

FOR THREE OR MORE IN PARALLEL, GO FIND YOUR CALCULATOR BECAUSE...

$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \ldots \text{ETC.}}$$

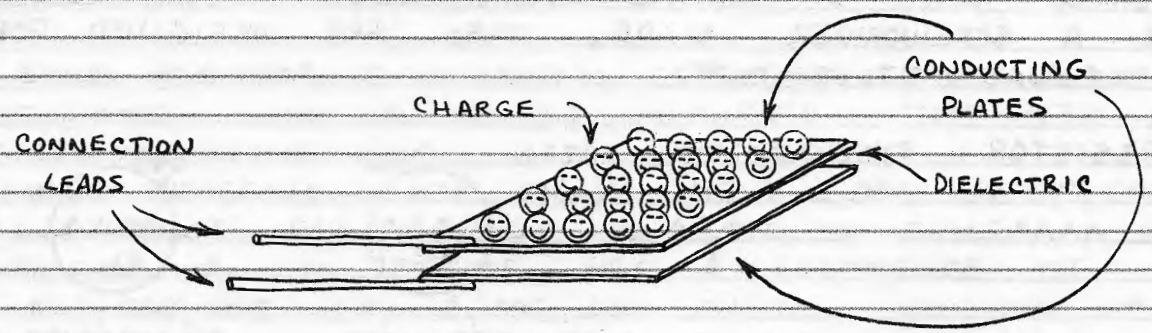
☐ VOLTAGE DIVISION — SUPER IMPORTANT! V_{OUT} IS DETERMINED BY RATIO OF R1 AND R2. HERE'S THE FORMULA:

$$V_{OUT} = V_{IN}\left(\frac{R2}{R1 + R2}\right)$$



CAPACITORS

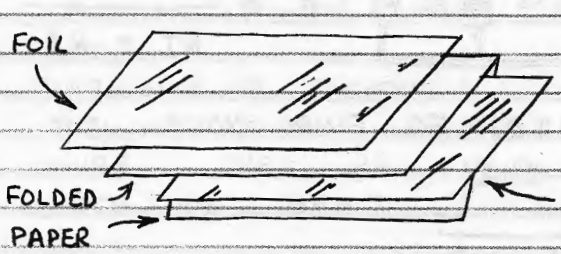
THERE ARE MANY KINDS OF CAPACITORS, BUT THEY ALL DO THE SAME THING: STORE ELECTRONS. THE SIMPLEST CAPACITOR IS TWO CONDUCTORS SEPARATED BY AN INSULATING MATERIAL CALLED THE DIELECTRIC. LIKE THIS:



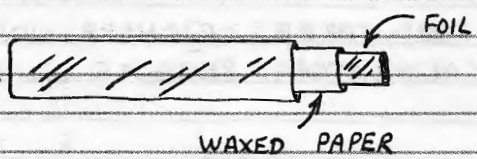
THE DIELECTRIC CAN BE PAPER, PLASTIC FILM, MICA, GLASS, CERAMIC, AIR OR A VACUUM. THE PLATES CAN BE ALUMINUM DISCS, ALUMINUM FOIL OR A THIN FILM OF METAL APPLIED TO OPPOSITE SIDES OF A SOLID DIELECTRIC. THE CONDUCTOR – DIELECTRIC – CONDUCTOR SANDWICH CAN BE ROLLED INTO A CYLINDER OR LEFT FLAT. MORE ABOUT TYPES OF CAPACITORS LATER.

HOW TO MAKE A CAPACITOR

YOU CAN MAKE A CAPACITOR FROM TWO SHEETS OF ALUMINUM FOIL AND ONE SHEET OF WAXED PAPER. FOLD THE PAPER AROUND ONE FOIL SHEET AND STACK THE SHEETS LIKE THIS:

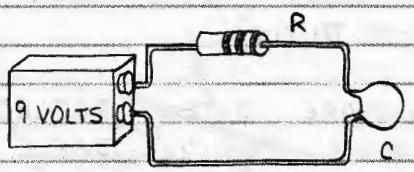


THEN FOLD THE SHEETS LIKE THIS:

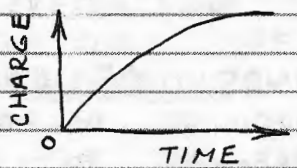


BE SURE THE FOIL SHEETS DON'T TOUCH! PRESS THE CONTACTS OF A 9-VOLT BATTERY BRIEFLY TO THE EXPOSED ENDS OF THE FOIL SHEETS. THEN TOUCH THE PROBES OF A HIGH-IMPEDANCE MULTIMETER TO THE FOIL SHEETS. THE METER WILL INDICATE A SMALL VOLTAGE FOR A FEW SECONDS. THE VOLTAGE WILL THEN FALL TO ZERO.

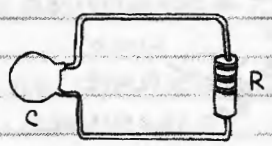
☐ CHARGING A CAPACITOR — THE MINUS SIDE OF OUR HOMEMADE CAPACITOR IS CHARGED WITH ELECTRONS ALMOST IMMEDIATELY. SINCE RESISTORS LIMIT CURRENT YOU CAN SLOW DOWN THE CHARGING TIME BY PLACING A RESISTOR BETWEEN THE CAPACITOR AND THE 9-VOLT BATTERY:



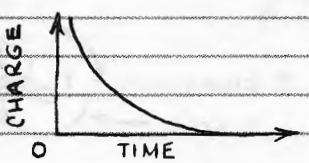
HERE'S A GRAPH OF THE CHARGING TIME:



☐ DISCHARGING A CAPACITOR — THE ELECTRONS IN A CHARGED CAPACITOR WILL GRADUALLY LEAK THROUGH THE DIELECTRIC UNTIL BOTH PLATES HAVE AN EQUAL CHARGE. THE CAPACITOR IS THEN DISCHARGED. THE CAPACITOR CAN BE DISCHARGED VERY QUICKLY BY CONNECTING ITS PLATES TOGETHER. OR IT CAN BE DISCHARGED MORE SLOWLY BY CONNECTING A RESISTOR ACROSS IT:



HERE'S A GRAPH OF THE DISCHARGE TIME:

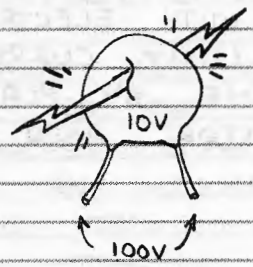


☐ SPECIFYING CAPACITORS — THE ABILITY TO STORE ELECTRONS IS KNOWN AS CAPACITANCE. CAPACITANCE IS SPECIFIED IN FARADS. A 1-FARAD CAPACITOR CONNECTED TO A 1-VOLT SUPPLY WILL STORE 6,280,000,000,000,000,000 (6.28×10^{18}) ELECTRONS! MOST CAPACITORS HAVE MUCH SMALLER VALUES. SMALL CAPACITORS ARE SPECIFIED IN PICOFARADS (TRILLIONITHS OF A FARAD) AND LARGER CAPACITORS ARE SPECIFIED IN MICROFARADS (MILLIONTHS OF A FARAD). SUMMING UP:

1-FARAD = 1 F
1-MICROFARAD = $1\,\mu F = 10^{-6}$ F = 0.000 001 F
1-PICOFARAD = $1\,pF = 10^{-12}$ F = 0.000 000 000 001 F

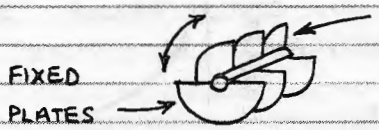
☐ SUBSTITUTING CAPACITORS — THE CAPACITANCE SPECIFIED FOR MOST CAPACITORS MAY BE FROM 5 TO 100 % AWAY FROM THE ACTUAL VALUE. THEREFORE YOU CAN OFTEN SUBSTITUTE CLOSE VALUES FOR A SPECIFIED VALUE. BE SURE, HOWEVER, TO USE A CAPACITOR RATED AT THE EXPECTED MAXIMUM VOLTAGE LEVEL!

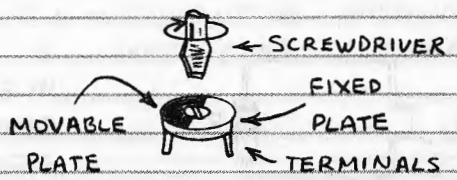
☐ CAPACITOR SUBSTITUTION PRECAUTIONS — YOU MUST MAKE SURE THE CAPACITOR YOU PLAN TO USE MEETS OR EXCEEDS THE REQUIRED VOLTAGE RATING. OTHERWISE ITS DIELECTRIC MAY BE ZAPPED BY THE STORED CHARGE. THE VOLTAGE RATING IS USUALLY PRINTED ON THE CAPACITOR. V MEANS VOLTS. WV IS WORKING VOLTS (SAME THING).



☐ KINDS OF CAPACITORS — CAPACITORS ARE OFTEN LABELED ACCORDING TO THEIR DIELECTRIC. THUS YOU'LL SEE REFERENCES TO CERAMIC, MICA, POLYSTYRENE AND MANY OTHERS. ALL THESE ARE FIXED VALUE CAPACITORS. SOME CAPACITORS HAVE A VARIABLE CAPACITY AND A SPECIAL CLASS OF FIXED CAPACITORS HAS MUCH MORE CAPACITY THAN OTHER CAPACITORS. HERE'S MORE:

VARIABLE CAPACITORS. THESE USUALLY HAVE ONE OR MORE NON-MOVING PLATES AND ONE OR MORE MOVING PLATES. THE CAPACITANCE IS CHANGED BY ROTATING A ROD AFFIXED TO ONE SIDE OF THE MOVABLE PLATES.

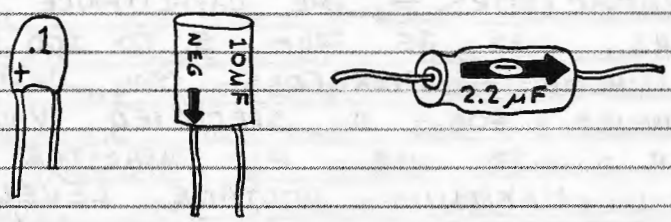




THIS KIND IS USED TO TUNE RADIO RECEIVERS AND TRANSMITTERS. THE DIELECTRIC IS USUALLY AIR.

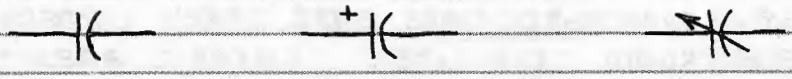
THIS KIND IS USED TO TUNE OSCILLATORS LIKE THOSE USED IN DIGITAL WATCHES. THEY'RE SMALL.

ELECTROLYTIC CAPACITORS. UNIQUE IN THAT A THIN OXIDE LAYER FORMED ON ALUMINUM OR TANTALUM FOIL IS THE DIELECTRIC. MUCH HIGHER CAPACITANCE THAN NON-ELECTROLYTIC TYPES. TANTALUM UNITS HAVE MORE CAPACITANCE PER VOLUME AND A LONGER LIFE THAN ALUMINUM ELECTROLYTICS. BUT THEY COST MORE. MOST ELECTROLYTICS ARE POLARIZED. THEY MUST BE CONNECTED INTO A CIRCUIT IN THE PROPER DIRECTION:



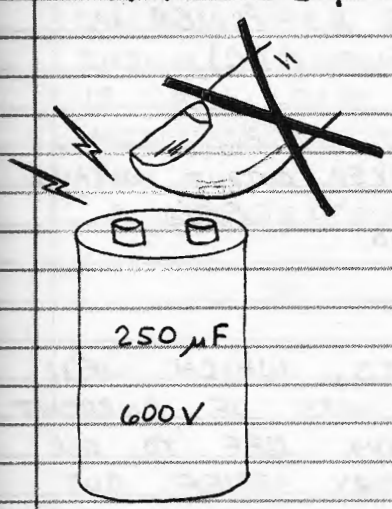
POSITIVE LEAD MUST GO TO MOST POSITIVE CONNECTION POINT!

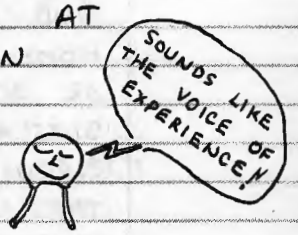
☐ CAPACITOR SYMBOLS:



FIXED FIXED VARIABLE

☐ WARNING! CAPACITORS CAN STORE A CHARGE FOR A CONSIDERABLE TIME AFTER THE POWER TO THEM HAS BEEN SWITCHED OFF. THIS CHARGE CAN BE DANGEROUS! A LARGE ELECTROLYTIC CHARGED TO ONLY 5 OR 10 VOLTS CAN MELT THE TIP OF A SCREWDRIVER PLACED ACROSS ITS TERMINALS! HIGH VOLTAGE CAPACITORS LIKE THOSE USED IN TELEVISION SETS AND PHOTOFLASH UNITS CAN STORE A LETHAL CHARGE! NEVER TOUCH THE LEADS OF SUCH A CAPACITOR. AT THE VERY LEAST THE JOLT CAN THROW YOU ACROSS A ROOM!

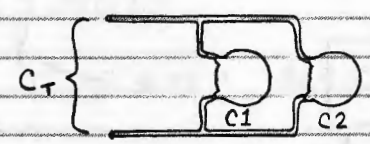




HOW CAPACITORS ARE USED

☐ PARALLEL CIRCUIT — OFTEN CAPACITORS ARE CONNECTED IN PARALLEL LIKE THIS:

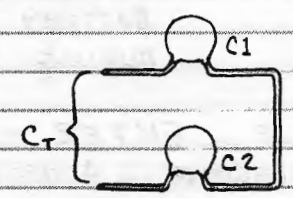
THE TOTAL CAPACITANCE IS THE SUM OF THE INDIVIDUAL CAPACITANCES.



$$C_T = C1 + C2$$

☐ SERIES CIRCUIT — SOMETIMES CAPACITORS ARE CONNECTED IN SERIES LIKE THIS:

THE TOTAL CAPACITANCE IS THE PRODUCT OF THE TWO CAPACITANCES DIVIDED BY THEIR SUM.



$$C_T = \frac{C1 \times C2}{C1 + C2}$$

THREE OR MORE CAPACITORS IN SERIES? HERE'S THE FORMULA:

$$C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} \ldots \text{ETC.}}$$

☐ AND MORE — THERE ARE MANY OTHER WAYS TO USE CAPACITORS, SOME OF WHICH ARE SHOWN NEXT . . .