

GETTING STARTED IN ELECTRONICS

BY
FORREST M. MIMS III

COPYRIGHT © 1983, 2000 BY FORREST M. MIMS, III
ALL RIGHTS RESERVED

Published for Forrest M. Mims III by:

MASTER PUBLISHING, INC.

7101 N. Ridgeway Ave.

Lincolnwood, IL 60712

847-763-0916 (voice)

847-763-0918 (fax)

masterpubl@aol.com (e-mail)

Visit Master Publishing
on the Internet at:

www.masterpublishing.com

REGARDING THESE BOOK MATERIALS

Reproduction, publication, or duplication of this book, or any part thereof, in any manner, mechanically, electronically, or photographically, is prohibited without the express written permission of the Author and Publisher. For permission and other rights under this copyright, write Master Publishing, Inc.

The Author, Publisher, and Seller assume no liability with respect to the use of the information contained herein.

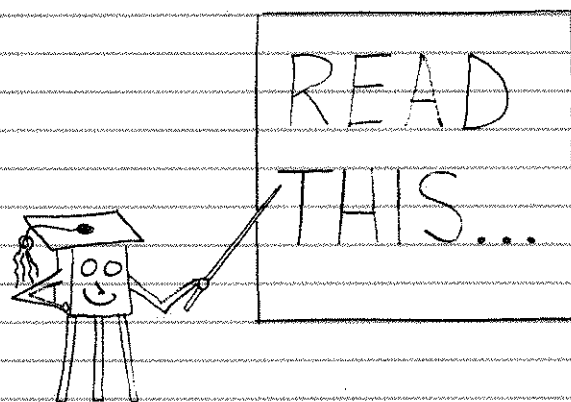
First edition:
Fifteen printings

Second edition:
First printing-1998

Third edition:
Second printing-2003

Third edition:
Third printing-2006

Fourth edition:
Fourth printing-2007



THIS BOOK IS FOR THE ENTERTAINMENT AND EDIFICATION OF ITS READERS. WHILE REASONABLE CARE HAS BEEN EXERCISED WITH RESPECT TO ITS ACCURACY, THE AUTHOR AND RADIO SHACK ASSUME NO RESPONSIBILITY FOR ERRORS, OMISSIONS OR SUITABILITY OF ITS CONTENTS FOR ANY APPLICATION. NEITHER DO WE ASSUME ANY LIABILITY FOR ANY DAMAGES RESULTING FROM USE OF INFORMATION IN THIS BOOK. IT IS YOUR RESPONSIBILITY TO DETERMINE IF USE, MANUFACTURE OR SALE OF ANY DEVICE THAT INCORPORATES INFORMATION IN THIS BOOK INFRINGES ANY PATENTS, COPYRIGHTS OR OTHER RIGHTS.

CAUTION: THIS BOOK INCLUDES SEVERAL REFERENCES TO ELECTRICAL SAFETY WHICH MUST BE HEEDED. IT IS ESSENTIAL THAT CAREFUL SUPERVISION BE GIVEN CHILDREN WORKING WITH LINE-POWERED ELECTRONIC CIRCUITS AND SOLDERING IRONS.

DUE TO THE MANY CUSTOMER INQUIRIES RECEIVED BY RADIOSHACK AND THE AUTHOR, IT IS IMPOSSIBLE TO ANSWER REQUESTS FOR ADDITIONAL INFORMATION (CUSTOM CIRCUIT DESIGNS, TECHNICAL ADVICE, TROUBLESHOOTING ASSISTANCE, ETC.). BUT THOUGH WE CANNOT ACKNOWLEDGE INDIVIDUAL INQUIRIES, WE WILL BE HAPPY TO RECEIVE ANY COMMENTS, IMPRESSIONS OR SUGGESTIONS.

THANKS IN ADVANCE TO THOSE OF YOU WHO WRITE! BUT PLEASE REMEMBER WE ARE UNABLE TO GIVE YOU A PERSONAL REPLY.

CONTENTS

GETTING STARTED IN ELECTRONICS	5
1. ELECTRICITY	6
PUTTING ELECTRICITY TO WORK	7
BACK TO BASICS	8-9
STATIC ELECTRICITY	10-12
ELECTRICAL CURRENT	13
DIRECT CURRENT ELECTRICITY	14-17
ALTERNATING CURRENT ELECTRICITY	18
MEASURING AC AND DC	19
ELECTRICAL CIRCUITS	20-21
PULSES, WAVES, SIGNALS AND NOISE	22-23
2. ELECTRONIC COMPONENTS	24
WIRE AND CABLE	24
SWITCHES	25
RELAYS	26
MOVING COIL METERS	26
MICROPHONES AND SPEAKERS	27
RESISTORS	28-31
CAPACITORS	32-35
RESISTOR AND CAPACITOR APPLICATIONS	36-37
COILS	38-39
TRANSFORMERS	40-41
3. SEMICONDUCTORS	42
SILICON	42-43
THE DIODE	44-47
THE TRANSISTOR	48
BIPOLAR TRANSISTORS	48-51
FIELD-EFFECT TRANSISTORS	52-56
THE UNIJUNCTION TRANSISTOR	57
THE THYRISTOR	58
SILICON-CONTROLLED RECTIFIERS	58-59
TRIACS	60-61
4. PHOTONIC SEMICONDUCTORS	62
LIGHT	62-63
OPTICAL COMPONENTS	64
HOW CONVEX LENSES ARE USED	65
SEMICONDUCTOR LIGHT SOURCES	66
LIGHT EMITTING DIODES	66-69
SEMICONDUCTOR LIGHT DETECTORS	70
PHOTORESISTIVE LIGHT DETECTORS	70-71
PN JUNCTION LIGHT DETECTORS	72
PHOTODIODES	72-73
PHOTOTRANSISTORS	74-75
PHOTOTHYRISTORS	76
SOLAR CELLS	77

5. INTEGRATED CIRCUITS	78-79
6. DIGITAL INTEGRATED CIRCUITS	80
MECHANICAL SWITCH GATES	80
THE BINARY CONNECTION	81
DIODE GATES	82
TRANSISTOR GATES	83
GATE SYMBOLS	84-85
DATA HIGHWAYS	85
HOW GATES ARE USED	86
COMBINATIONAL LOGIC CIRCUITS	86-87
SEQUENTIAL LOGIC CIRCUITS	88-89
A COMBINATIONAL-SEQUENTIAL LOGIC SYSTEM	90
DIGITAL IC FAMILIES	91
7. LINEAR INTEGRATED CIRCUITS	92
THE BASIC LINEAR CIRCUIT	92
OPERATIONAL AMPLIFIERS	93
TIMERS	94
FUNCTION GENERATORS	94
VOLTAGE REGULATORS	95
OTHER LINEAR IC'S	95
8. CIRCUIT ASSEMBLY TIPS	96
TEMPORARY CIRCUITS	96
PERMANENT CIRCUITS	96-97
HOW TO SOLDER	98
POWERING ELECTRONIC CIRCUITS	99
9. 100 ELECTRONIC CIRCUITS	100
DIODE CIRCUITS	101
SMALL SIGNAL DIODES AND RECTIFIERS	101-102
ZENER DIODE CIRCUITS	103
TRANSISTOR CIRCUITS	104
BIPOLAR TRANSISTOR CIRCUITS	104-105
JUNCTION FET AND POWER MOSFET CIRCUITS	106-107
UNIJUNCTION TRANSISTOR CIRCUITS	108-109
THYRISTOR CIRCUITS	110
SCR CIRCUITS	110
TRIAC CIRCUITS	111
PHOTONIC CIRCUITS	112
LIGHT EMITTING DIODE (LED) CIRCUITS	112-113
SEMICONDUCTOR LIGHT DETECTOR CIRCUITS	114-115
DIGITAL IC CIRCUITS	116
TTL CIRCUITS	116-117
CMOS CIRCUITS	118-121
LINEAR IC CIRCUITS	122
OPERATIONAL AMPLIFIER (OP-AMP) CIRCUITS	122-123
COMPARATOR CIRCUITS	124
VOLTAGE REGULATOR CIRCUITS	125
TIMER CIRCUITS	126-127
INDEX	128

GETTING STARTED IN ELECTRONICS

WELCOME TO THE WORLD OF ELECTRONICS, ONE OF THE FASTEST GROWING OF TODAY'S "HIGH-TECH" FIELDS AND AN EDUCATIONAL AND ENTERTAINING HOBBY. THIS BOOK WILL TAKE YOU FROM STATIC ELECTRICITY TO SOLID-STATE ELECTRONICS. ALONG THE WAY WE'LL COVER ELECTRICITY, ELECTRONIC COMPONENTS AND INTEGRATED CIRCUITS (IC's). CHAPTERS 3-7 SHOW HOW COMPONENTS ARE USED TO FORM ELECTRONIC CIRCUITS. CHAPTER 9 GIVES PLANS FOR 100 CIRCUITS, EACH OF WHICH I'VE BUILT AND TESTED. "PAGE ARROWS" (➡) THROUGHOUT THE BOOK REFER YOU TO RELATED TOPICS IN FUTURE CHAPTERS (LIKE WORKING VERSIONS OF MANY EXAMPLE CIRCUITS IN CHAPTERS 3-7). I HOPE YOU FIND THIS BOOK USEFUL, EDUCATIONAL AND, ESPECIALLY, FUN! Forrest M. Mims III

GOING FURTHER IN ELECTRONICS

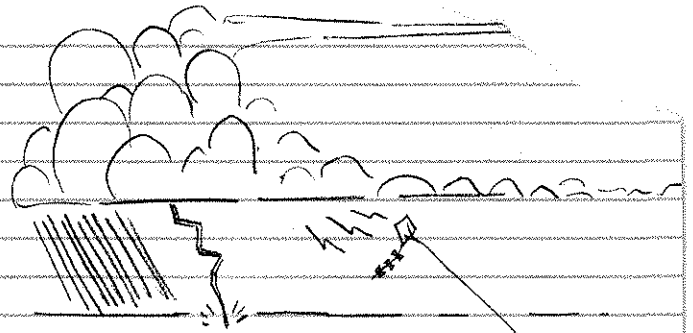
I HOPE THIS BOOK ENCOURAGES YOU TO GO FURTHER IN ELECTRONICS. YOU CAN BEGIN BY BUILDING THE HUNDREDS OF CIRCUITS IN THE "ENGINEER'S MINI-NOTEBOOK" SERIES I HAVE WRITTEN FOR RADIOSHACK. YOU SHOULD ALSO READ HOBBY ELECTRONICS MAGAZINES. REMEMBER THIS: YOU WILL LEARN MORE FROM BUILDING, TESTING AND USING ELECTRONIC CIRCUITS THAN BY SIMPLY READING ABOUT THEM. SO BE SURE TO ACTUALLY BUILD AS MANY OF THE CIRCUITS IN THIS BOOK AS YOU CAN. QUESTIONS? THIS BOOK WILL RAISE LOTS OF QUESTIONS IF YOU'RE SERIOUS ABOUT ELECTRONICS. YOU CAN FIND ANSWERS TO MANY OF YOUR QUESTIONS IN THE "ENGINEER'S MINI-NOTEBOOK" SERIES AND OTHER RADIOSHACK BOOKS. BE SURE TO SEE THE BOOKS ABOUT ELECTRONICS AT THE LOCAL LIBRARY. FINALLY, BE SURE TO CHECK OUT THE VARIOUS HOBBY ELECTRONICS NEWS GROUPS AND RESOURCES—INCLUDING RADIOSHACK'S—ON THE INTERNET AND WORLD WIDE WEB.

A SPECIAL NOTE TO EDUCATORS

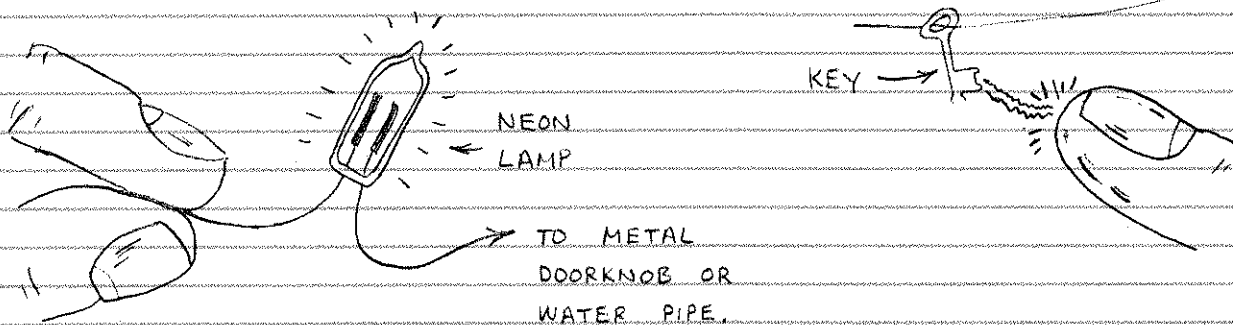
SINCE THIS BOOK WAS FIRST PUBLISHED IN 1983, IT HAS HELPED MANY STUDENTS DEVELOP AWARD WINNING SCIENCE PROJECTS. SOME TEACHERS ASSIGN VARIOUS SECTIONS OF THE BOOK. OTHERS USE THE ENTIRE BOOK AS THE TEXT FOR COURSES ON BASIC ELECTRONICS. THANKS TO RADIOSHACK'S SOLDERLESS, MODULAR SOCKETS, YOU AND YOUR STUDENTS SHOULD BE ABLE TO ASSEMBLE TEST VERSIONS OF VIRTUALLY EVERY CIRCUIT IN CHAPTER 9 ("100 ELECTRONIC CIRCUITS"). INCIDENTALLY, VOLUME BUYERS SHOULD INQUIRE AT RADIOSHACK ABOUT VOLUME DISCOUNTS ON THIS BOOK AND RADIOSHACK PARTS. ALSO SEE RADIOSHACK'S CATALOG. (PRICE DISCOUNTS MAY NOT APPLY AT RADIOSHACK DEALERS AND FRANCHISE STORES.)

1. ELECTRICITY

THE ONLY DIFFERENCE BETWEEN A BOLT OF LIGHTNING AND THE SPARK BETWEEN YOUR FINGER AND A DOOR-KNOB ON A DRY DAY IS QUANTITY. BOTH ARE ELECTRICITY. BENJAMIN FRANKLIN FIRST CONFIRMED THIS WITH HIS FAMOUS KITE EXPERIMENT.

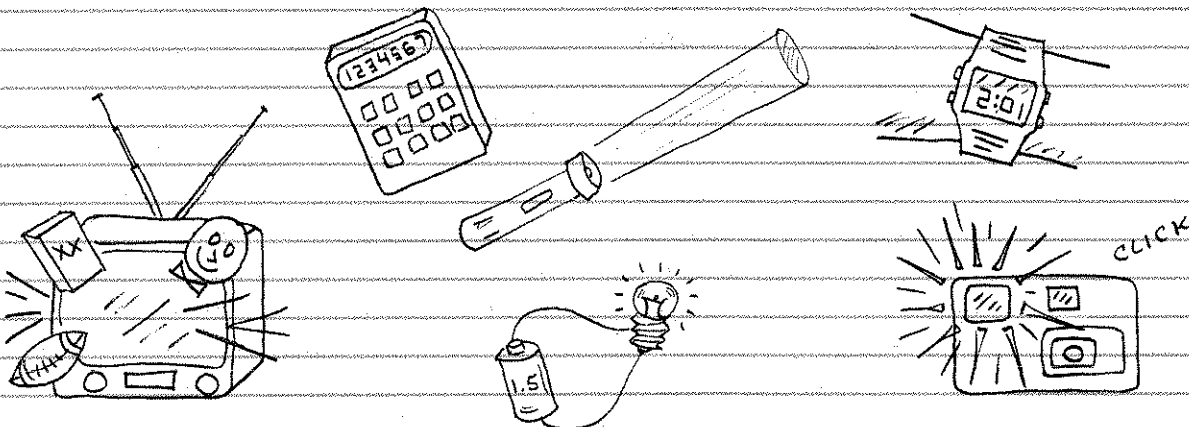


TO THOSE WHO FLY A KITE IN THE RAIN, YOU BETTER SAY "BYE!" 'CAUSE IT'S NOT VERY SAFE.



HERE'S A NEAT WAY TO "SEE" ELECTRICITY WITHOUT BEING ZAPPED: GRASP ONE LEAD FROM A NEON LAMP, WALK ACROSS A CARPET WHILE WEARING HARD SOLED SHOES AND TOUCH THE SECOND LEAD FROM THE LAMP TO A METAL OBJECT. THE LAMP WILL FLASH (UNLESS THE RELATIVE HUMIDITY IS HIGH).

OF COURSE, YOU CANNOT "SEE" ELECTRICITY! YOU SEE ITS EFFECT UPON AIR AND THE NEON IN THE LAMP. THE EFFECTS OF ELECTRICITY WHICH CAN BE SEEN ARE MANY. HERE ARE SOME MORE:

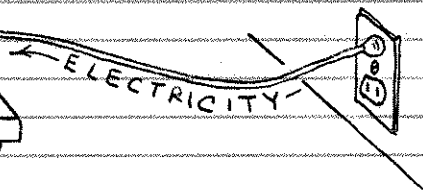
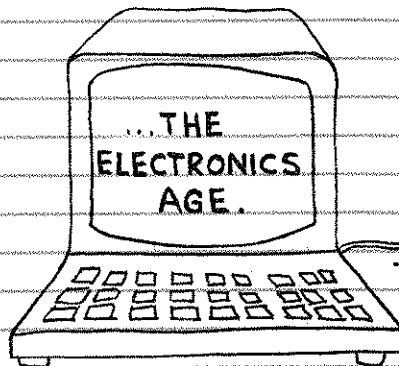


PUTTING ELECTRICITY TO WORK

ALL MATTER HAS ELECTRICAL PROPERTIES. THAT'S WHY SCIENTISTS OVER THE PAST FEW CENTURIES HAVE BEEN ABLE TO INVENT HUNDREDS OF GADGETS THAT GENERATE, STORE, CONTROL AND SWITCH ELECTRICITY. THESE DEVICES HAVE COMBINED TO CARRY US INTO...

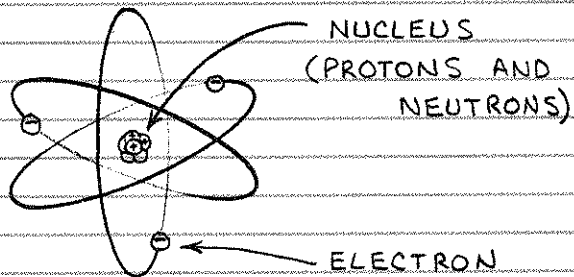
IN THE PAGES THAT FOLLOW YOU'LL FIND OUT HOW THESE AND OTHER ELECTRONIC PARTS WORK. AND YOU'LL LEARN HOW TO USE THEM IN WORKING ELECTRONIC CIRCUITS. LIKE... LIGHT FLASHERS, TIMERS, AMPLIFIERS, DIGITAL LOGIC CIRCUITS, POWER SUPPLIES, SOUND GENERATORS AND MANY OTHERS. AFTER YOU COMPLETE THIS BOOK, YOU'LL BE ABLE TO IDENTIFY AND USE ALL THE COMPONENTS SHOWN ON THIS PAGE! THEY INCLUDE A TRANSFORMER, DIODES, RESISTORS, CAPACITORS, ZENER DIODES, TRANSISTORS, VOLTAGE REGULATORS AND INTEGRATED CIRCUITS.

IF YOU'RE ANXIOUS TO GET STARTED WORKING WITH ELECTRONIC PARTS AND CIRCUITS, SKIP AHEAD TO CHAPTER TWO. WHEN YOU HAVE TIME, BE SURE TO GO OVER THE REST OF THIS CHAPTER. YOU'LL LEARN SOME BASIC FACTS ABOUT ELECTRICITY THAT WILL GIVE YOU A SOLID FOUNDATION FOR FURTHER LEARNING. AND YOU'LL FIND OUT HOW TO CREATE AND DETECT ELECTRICITY WITH ORDINARY HOUSEHOLD MATERIALS.



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.

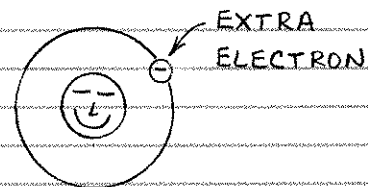


LITHIUM ATOM

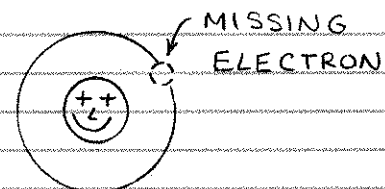
THIS IS A LITHIUM ATOM. THE THIRD SIMPLEST ATOM AFTER HYDROGEN AND HELIUM, LITHIUM ATOMS HAVE 3 ELECTRONS THAT ENCIRCLE A NUCLEUS OF 3 PROTONS AND 4 NEUTRONS.

- ⊖ 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

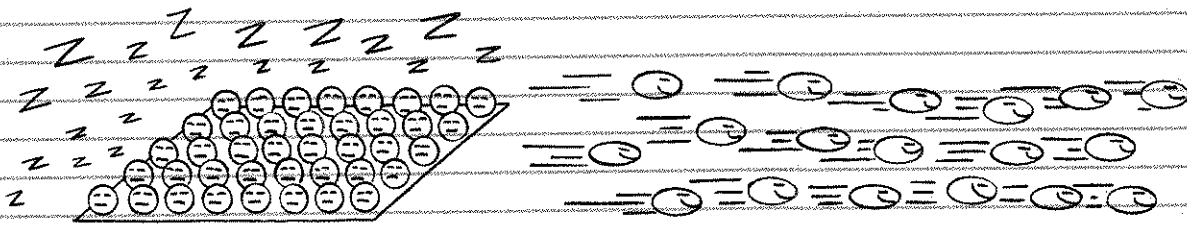


POSITIVE ION

□ 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)!

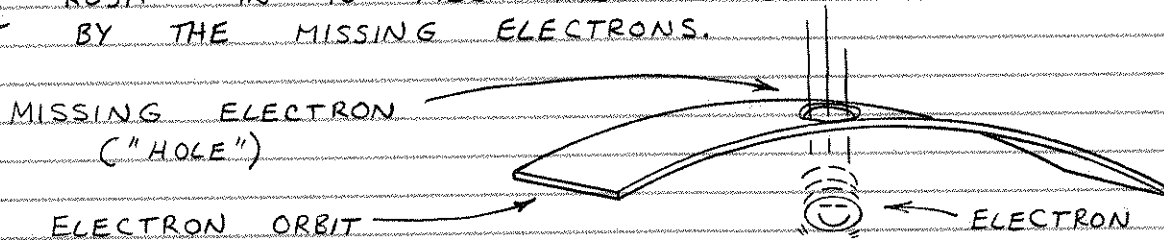


RESTING ELECTRONS

MOVING ELECTRONS

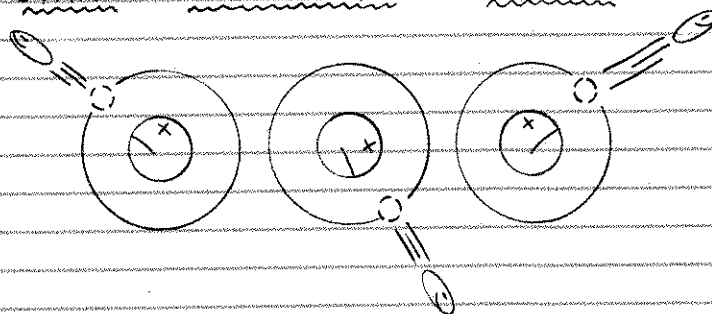
□ RESTING ELECTRONS — A GROUP OF NEGATIVE ELECTRONS ON A SURFACE CAUSES THE SURFACE TO BE NEGATIVELY CHARGED. SINCE THE ELECTRONS ARE NOT MOVING, THE SURFACE CAN BE SAID TO HAVE A NEGATIVE STATIC ELECTRICAL CHARGE.

□ 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.

FRICTION
LIGHT
HEAT
CHEMICALS

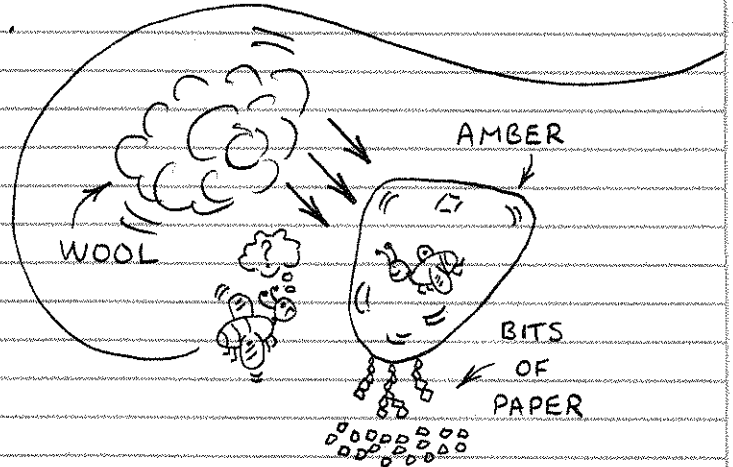


POSITIVE IONS
WITH POSITIVE
STATIC ELEC-
TRICAL CHARGE.

STATIC ELECTRICITY

YOU GENERATE STATIC ELECTRICITY EVERY TIME YOU WALK ACROSS A CARPET, PULL TAPE FROM A ROLL, REMOVE YOUR CLOTHING OR DRY CLOTHES IN A DRIER. MUCH OF THE TIME YOU DON'T EVEN REALIZE IT UNLESS THE AIR IS DRY AND THE STATIC CHARGE SUDDENLY CRACKLES, POPS AND FLASHES ITS WAY TO A NEW HOME. THESE STATIC CHARGES ARE CAUSED BY MECHANICAL FRICTION. BACK IN 600 B.C., THALES OF GREECE EXPERIMENTED WITH THE STATIC ELECTRICITY PRODUCED WHEN AMBER IS RUBBED WITH WOOL.

□ AMBER—ONCE UPON A TIME SAP FLOWING FROM TREES HARDENED INTO CLEAR GOLDEN NODULES WHICH WERE EVENTUALLY BURIED IN THE EARTH. SOMETIMES, BEFORE IT HARDENED INTO AMBER, THE STICKY SAP ENTOMBED BITS OF PLANT MATTER, INSECTS AND EVEN DROPLETS OF WATER! A KIND OF NATURAL CASTING PLASTIC, AMBER IS EASILY ELECTRIFIED BY FRICTION. IT THEN ATTRACTS BITS OF PAPER.

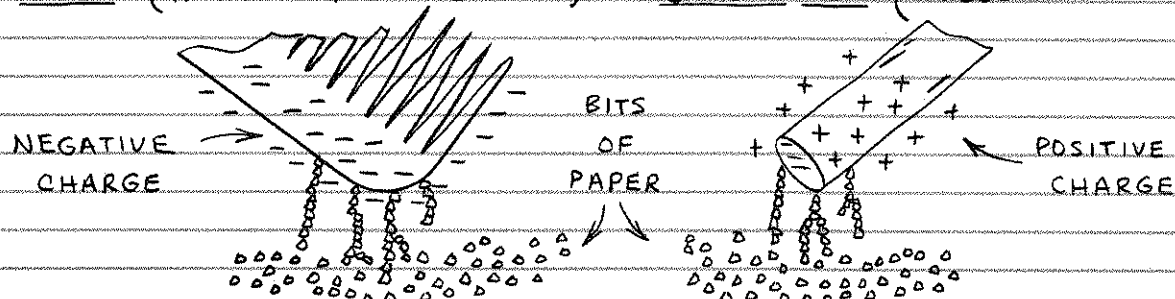


FAMOUS FACT: THE ELECTRON IS NAMED AFTER THE GREEK WORD FOR AMBER!

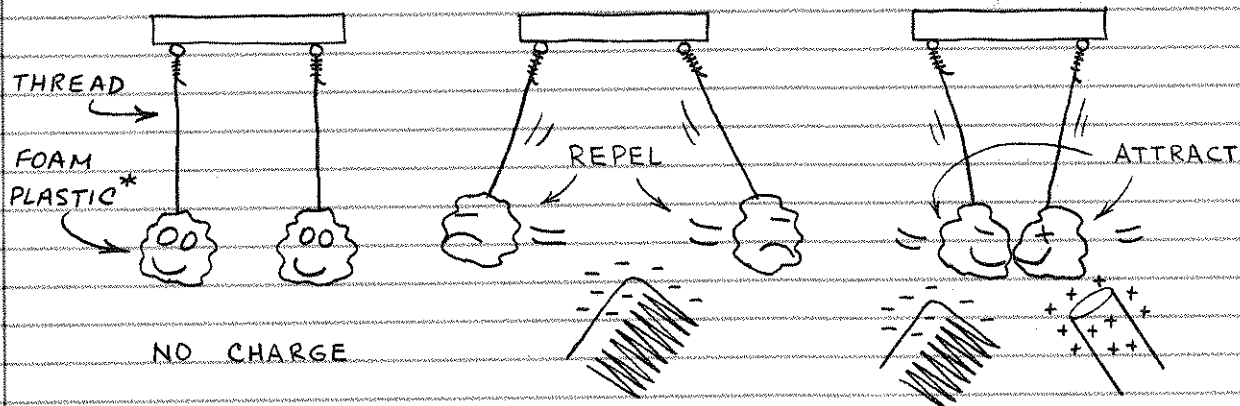
□ ELECTRIFIED PLASTIC AND GLASS—RUN A PLASTIC COMB THROUGH YOUR HAIR ON A DRY DAY AND YOU'LL TRANSFER ELECTRONS FROM YOUR HAIR TO THE COMB. RUB A GLASS ROD WITH SILK OR THE SYNTHETIC FIBERS OF A PAINT BRUSH AND YOU'LL REMOVE ELECTRONS FROM THE GLASS. BOTH THE NEGATIVELY CHARGED COMB AND THE POSITIVELY CHARGED GLASS ROD WILL, LIKE AMBER, ATTRACT BITS OF PAPER. YOU CAN ELECTRIFY OR CHARGE MANY MATERIALS BY RUBBING THEM WITH FUR, WOOL, ETC. METAL? NO, THE CHARGE LEAKS AWAY.

COMB (AFTER STROKING HAIR)

GLASS ROD (RUBBED WITH SILK)

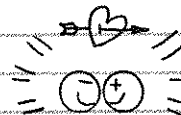


□ OPPOSITE AND LIKE CHARGES — HOW DO WE KNOW THE COMB AND GLASS ROD HAVE OPPOSITE CHARGES? A FUNDAMENTAL RULE OF ELECTRICITY IS LIKE CHARGES REPEL AND UNLIKE CHARGES ATTRACT. HERE'S AN EXPERIMENT THAT PROVES THE RULE AND ANSWERS THE QUESTION:

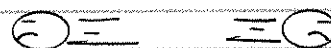


*USE FOAM PLASTIC PACKING MATERIAL.

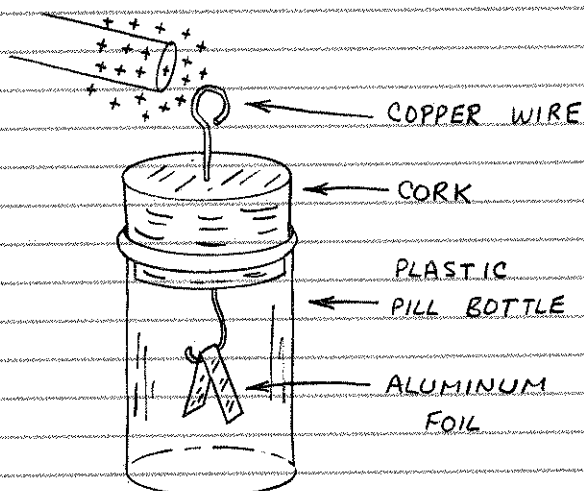
REMEMBER: UNLIKE CHARGES ATTRACT —



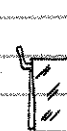
LIKE CHARGES REPEL —



□ THE ELECTROSCOPE — THE FIRST INSTRUMENT DESIGNED TO DETECT AND MEASURE STATIC ELECTRICITY WAS THE ELECTROSCOPE. YOU CAN EASILY MAKE ONE.



NO CHARGE —



MEDIUM CHARGE —



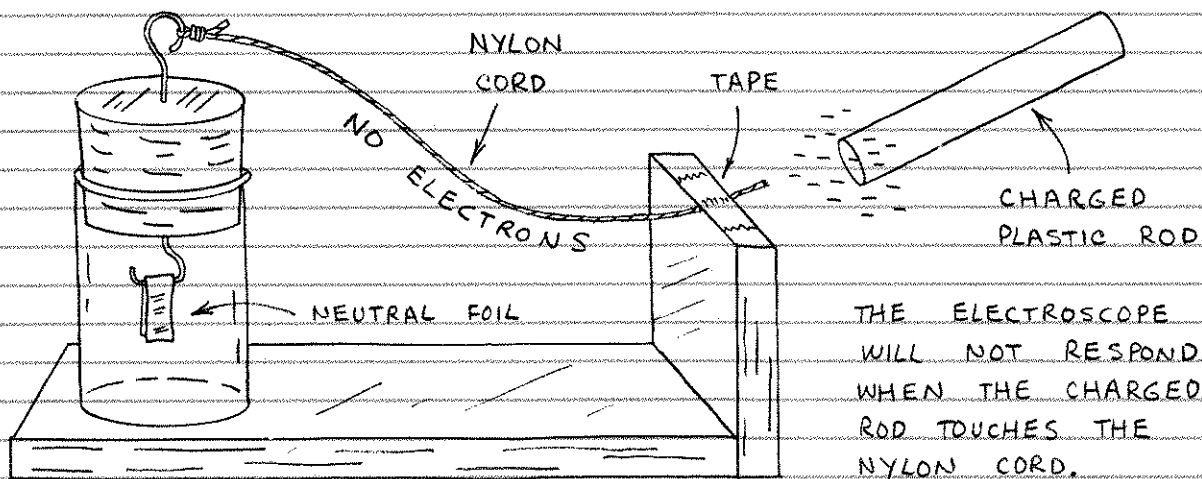
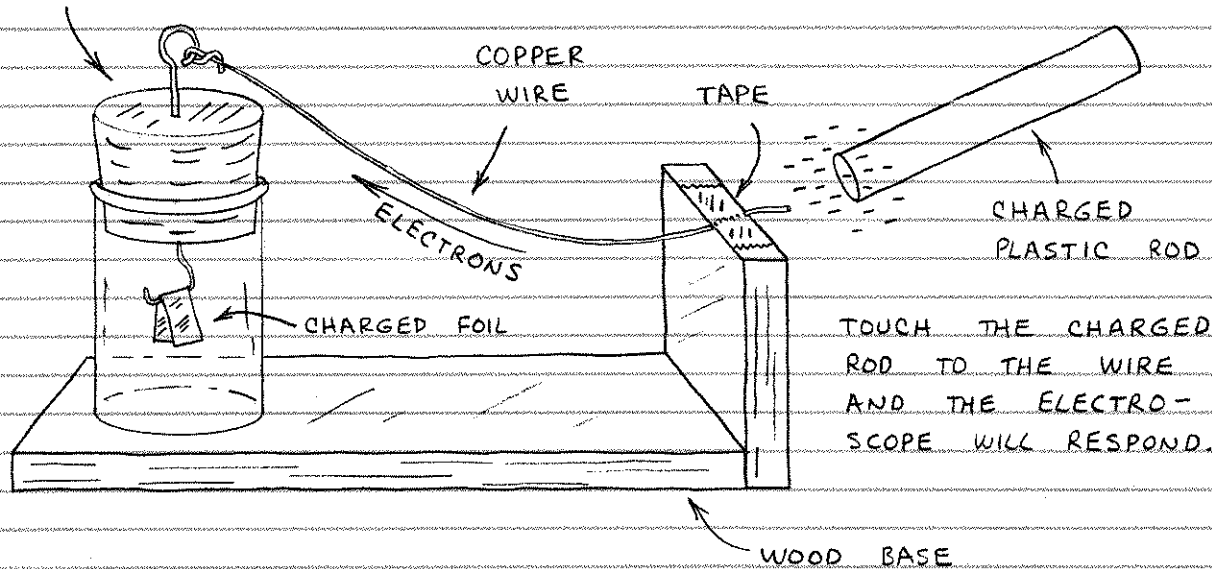
HIGH CHARGE —



BE SURE THE FOLDED FOIL STRIP IS CLEAN AND DRY. WHEN YOU TOUCH A CHARGED OBJECT TO THE WIRE, THE TWO HALVES OF THE FOIL STRIP WILL BE GIVEN THE SAME CHARGE AND WILL THEREFORE FLY APART.

□ CONDUCTORS AND INSULATORS - YOU CAN USE YOUR ELECTROSCOPE TO PROVE THAT ELECTRONS TRAVEL THROUGH SOME MATERIALS BUT NOT OTHERS. HINT: TRY THIS ON A DRY DAY! ELECTRONS CAN TRAVEL THROUGH MOIST AIR SO THE CHARGE ON YOUR ELECTROSCOPE WILL QUICKLY LEAK AWAY ON HUMID DAYS.

ELECTROSCOPE



THIS DEMONSTRATION SHOWS THAT ELECTRONS CAN TRAVEL THROUGH SOME MATERIALS BUT NOT OTHERS. MATERIALS THROUGH WHICH ELECTRONS TRAVEL ARE CONDUCTORS. MATERIALS THROUGH WHICH ELECTRONS TRAVEL POORLY OR NOT AT ALL ARE INSULATORS.

CONDUCTORS INCLUDE SILVER, GOLD, IRON, COPPER, ETC.

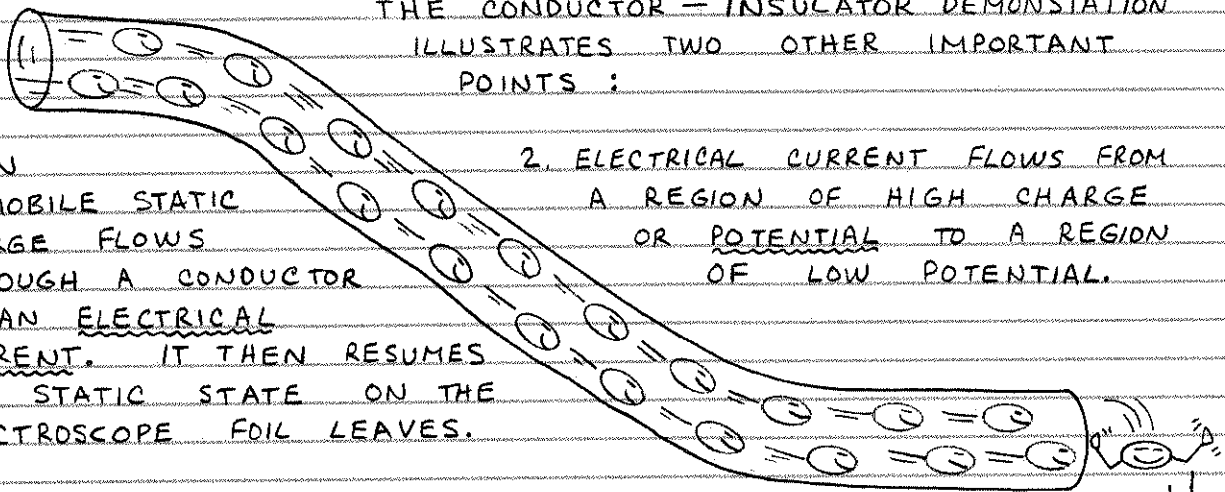
INSULATORS INCLUDE GLASS, PLASTIC, RUBBER, WOOD, ETC.

ELECTRICAL CURRENT

THE CONDUCTOR - INSULATOR DEMONSTRATION ILLUSTRATES TWO OTHER IMPORTANT POINTS :

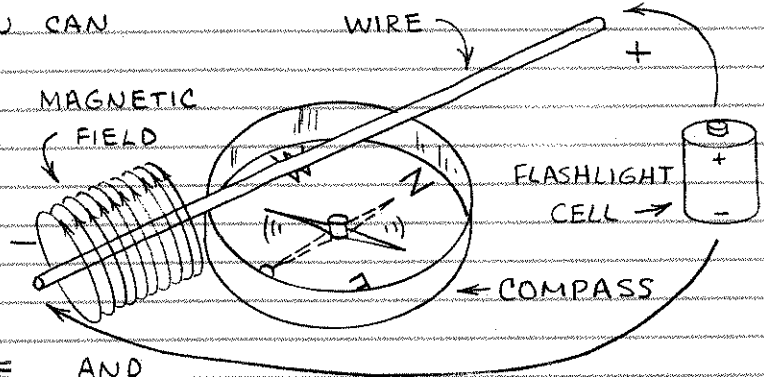
1. AN IMMOBILE STATIC CHARGE FLOWS THROUGH A CONDUCTOR AS AN ELECTRICAL CURRENT. IT THEN RESUMES ITS STATIC STATE ON THE ELECTROSCOPE FOIL LEAVES.

2. ELECTRICAL CURRENT FLOWS FROM A REGION OF HIGH CHARGE OR POTENTIAL TO A REGION OF LOW POTENTIAL.



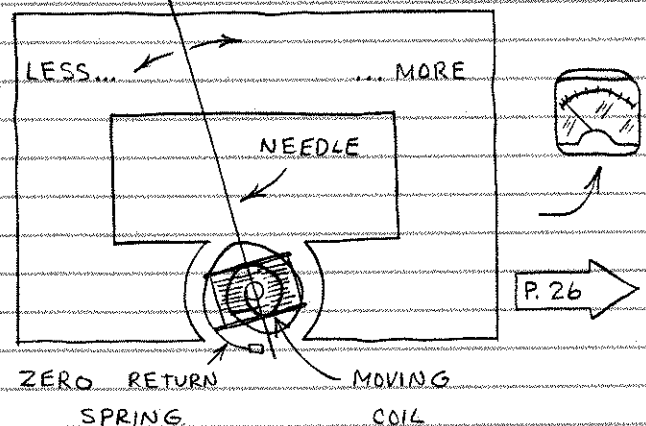
□ THE MAGNETIC CONNECTION - A CURRENT FLOWING THROUGH A WIRE CREATES A MAGNETIC FIELD AROUND THE WIRE. YOU CANNOT SEE THE FIELD, BUT YOU CAN OBSERVE ITS EFFECT.

ORIENT A COMPASS SO ITS NEEDLE POINTS TO THE NORTH (N) MARK. PLACE A COPPER WIRE OVER AND PARALLEL TO THE NEEDLE. THEN CONNECT A FLASHLIGHT CELL ACROSS THE WIRE AND THE NEEDLE WILL MOVE AWAY FROM ITS NORTH-SOUTH ORIENTATION. (LEAVE THE WIRE CONNECTED FOR ONLY AN INSTANT TO PREVENT THE CELL FROM OVERHEATING!)



□ MEASURING CURRENT ELECTRICITY -

THE PHYSICAL (OR MECHANICAL) MAGNET MOTION OF A MAGNETIC COMPASS NEEDLE IN A MAGNETIC FIELD PROVIDES A CONVENIENT WAY TO MEASURE THE QUANTITY OF CURRENT FLOWING IN A WIRE. THIS IS THE BASIS OF THE MOVING COIL CURRENT METER USED IN THE ANALOG MULTIMETER. TO PROVIDE HIGH SENSITIVITY, THE WIRE IS WRAPPED AS A COIL,



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:

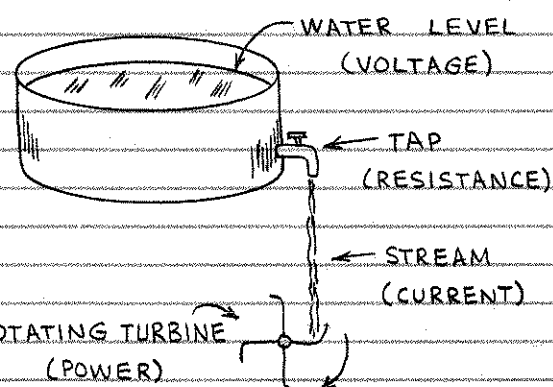
$$V = I \times R$$

$$I = V / R$$

$$R = V / I$$

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

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



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

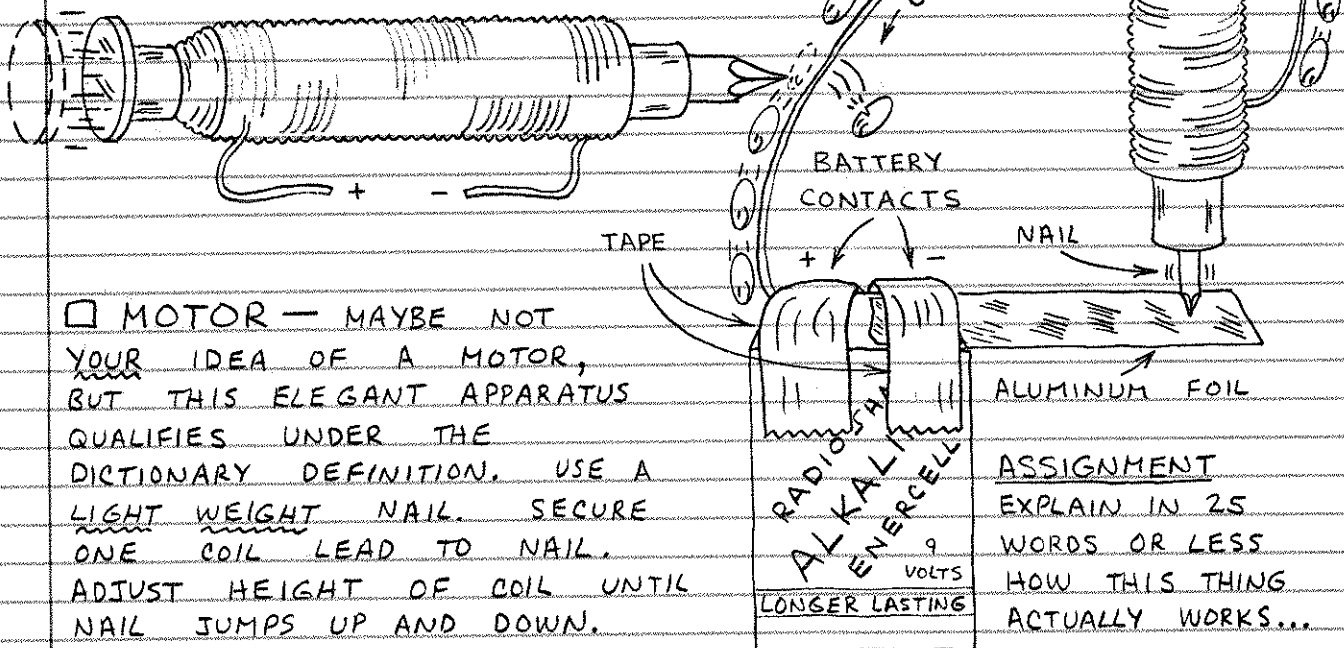
USING DIRECT CURRENT

THERE ARE SO MANY USES FOR DIRECT CURRENT ELECTRICITY NO SINGLE BOOK CAN DESCRIBE THEM ALL. HERE'S A PAGE OF SEVERAL DESIGNED AROUND A SINGLE WIRE COIL YOU CAN EASILY MAKE FROM A 1-1/2 TO 3-INCH SECTION OF A SODA STRAW AND AT LEAST 30-FEET OF 30 GAUGE, LACQUER COATED WIRE. SECURE THE COIL IN PLACE WITH TAPE. REMOVE INSULATION FROM ENDS OF COIL WITH FINE SAND PAPER.

(TWICE ACTUAL SIZE)

□ ELECTROMAGNET — INSERT A STEEL NAIL IN THE COIL, CONNECT THE LEADS TO A 9-VOLT BATTERY, AND THE NAIL WILL BECOME A MAGNET UNTIL THE POWER IS DISCONNECTED. (IT MAY RETAIN SOME MAGNETISM.)

□ SOLENOID — THIS IS A "SUCKING MAGNET." APPLY POWER TO COIL AND NAIL WILL BE PULLED RAPIDLY INSIDE.

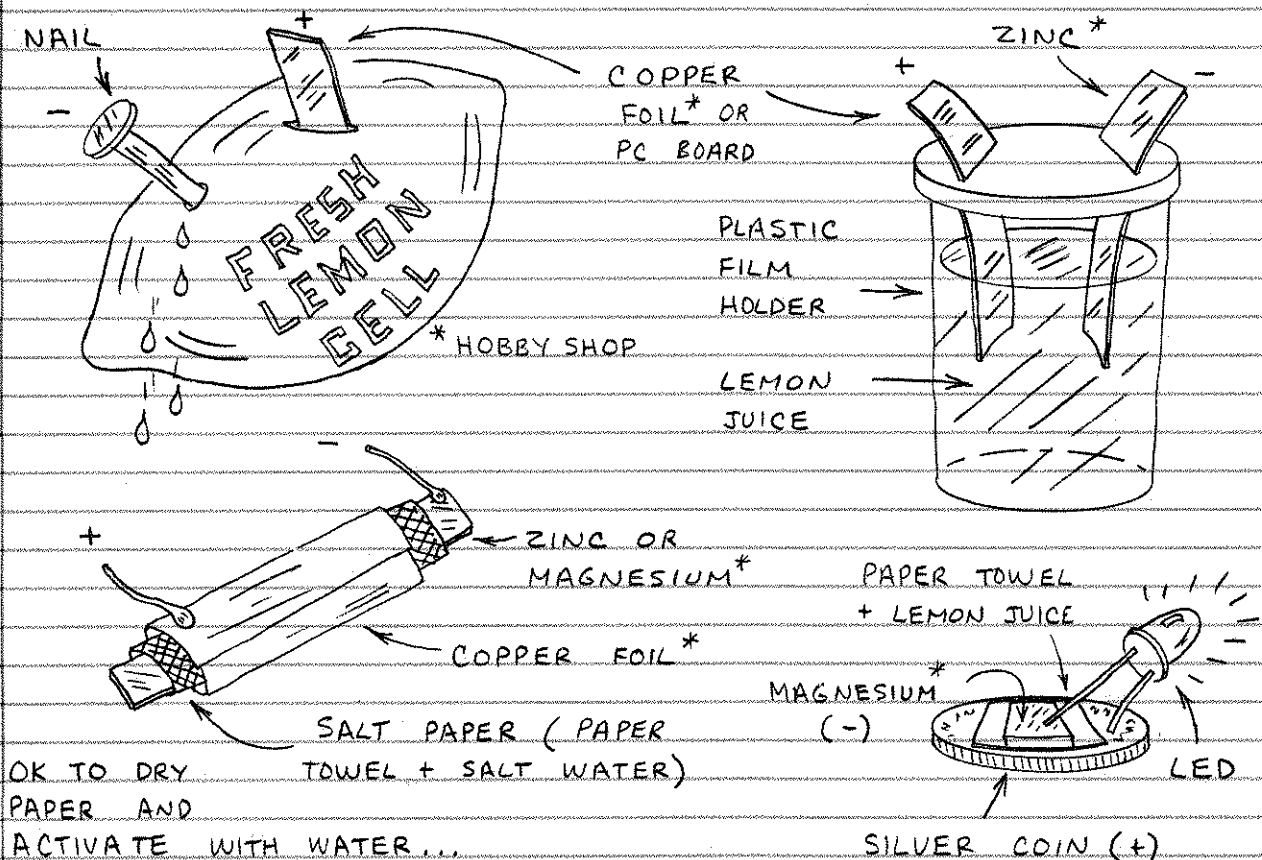


□ MOTOR — MAYBE NOT YOUR IDEA OF A MOTOR, BUT THIS ELEGANT APPARATUS QUALIFIES UNDER THE DICTIONARY DEFINITION. USE A LIGHT WEIGHT NAIL. SECURE ONE COIL LEAD TO NAIL. ADJUST HEIGHT OF COIL UNTIL NAIL JUMPS UP AND DOWN.

MAKING DIRECT CURRENT ELECTRICITY

A SURPRISING NUMBER OF WAYS EXIST FOR PRODUCING DIRECT CURRENT. HERE ARE THE BIGGIES:

☐ CHEMICAL GENERATORS — ELECTROLYTES ARE CHEMICAL SOLUTIONS THAT CONTAIN MANY IONS. FOR EXAMPLE, DISSOLVE TABLE SALT IN WATER AND THE SALT WILL BREAK DOWN INTO POSITIVE SODIUM IONS AND NEGATIVE CHLORINE IONS. IF TWO DISSIMILAR METAL PLATES ARE IMMERSSED IN THE SALT SOLUTION, THE POSITIVE IONS WILL MIGRATE TOWARD ONE PLATE AND THE NEGATIVE IONS WILL MIGRATE TOWARD THE OTHER. IF THE TWO PLATES ARE CONNECTED TOGETHER BY A CONDUCTOR, A CURRENT WILL FLOW THROUGH THE SOLUTION (AS IONS) AND THE CONDUCTOR (AS ELECTRONS). THIS KIND OF GENERATOR IS CALLED A WET CELL. CELLS IN WHICH THE ELECTROLYTE IS ABSORBED BY PAPER OR FORMED INTO A PASTE ARE CALLED DRY CELLS. HERE ARE SOME CHEMICAL GENERATORS YOU CAN MAKE. HAVE FUN!



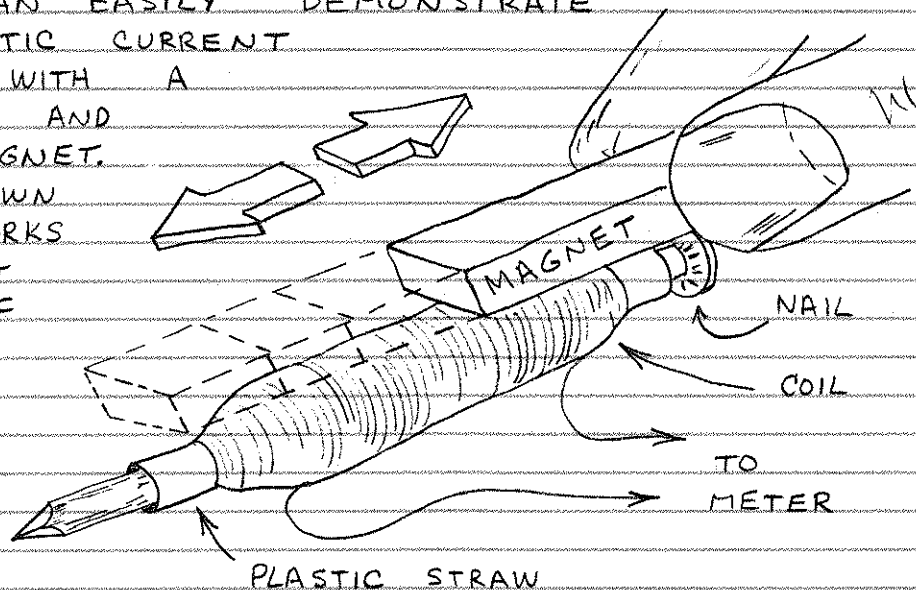
CONNECT TWO OR MORE CELLS IN SERIES TO FORM A BATTERY WITH TOTAL VOLTAGE EQUAL TO SUM OF CELL VOLTAGES.



□ ELECTROMAGNETIC GENERATORS — A CURRENT FLOWING THROUGH A CONDUCTOR ESTABLISHES A MAGNETIC FIELD AROUND THE CONDUCTOR. THIS EFFECT WORKS BOTH WAYS SO THAT A CURRENT WILL FLOW IN A CONDUCTOR WHICH IS MOVED THROUGH A MAGNETIC FIELD. YOU CAN EASILY DEMONSTRATE ELECTROMAGNETIC CURRENT GENERATION WITH A COIL OF WIRE AND A SMALL MAGNET.

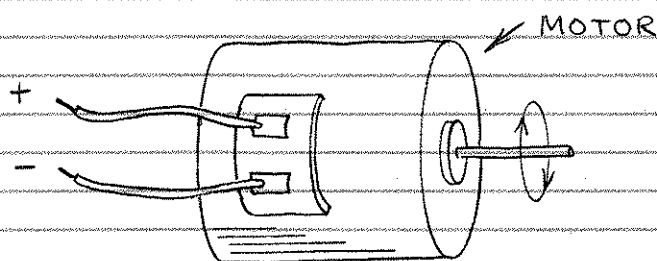
(THE COIL SHOWN ON PAGE 15 WORKS FINE.)

CONNECT THE LEADS OF THE COIL TO A METER DESIGNED TO SENSE MICROAMPERES. INSERT A STEEL NAIL

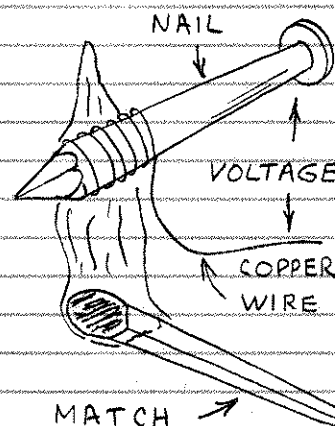


THROUGH THE COIL AND STROKE THE MAGNET BACK AND FORTH ACROSS THE COIL. THE METER WILL INDICATE A FEW MICROAMPERES EACH STROKE. THE POLARITY (DIRECTION) OF THE CURRENT WILL REVERSE ON THE BACK STROKES. WANT A READY-MADE GENERATOR? JUST ROTATE THE SHAFT OF A SMALL DC MOTOR.

MOST SUCH MOTORS WILL PRODUCE A POTENTIAL DIFFERENCE OF UP TO SEVERAL VOLTS! YOU CAN ADD A PROPELLER TO MAKE A WIND POWERED GENERATOR.

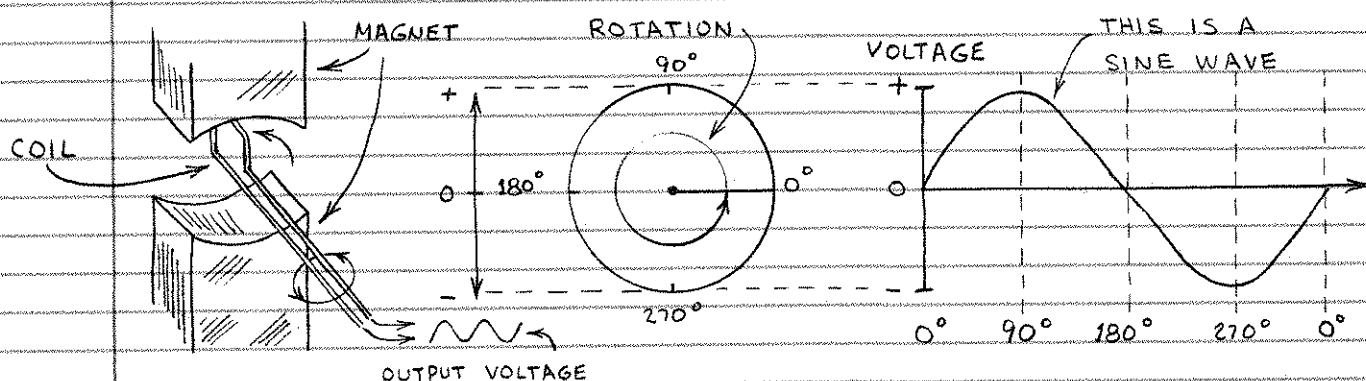


□ THERMOELECTRIC GENERATORS — IF A JUNCTION OF TWO DISSIMILAR METALS IS HEATED, A CURRENT WILL BE PRODUCED. COPPER WIRE WRAPPED AROUND THE END OF A STEEL NAIL WILL GENERATE A FEW THOUSANDTHS OF A VOLT WHEN HEATED BY THE FLAME OF A MATCH. JUNCTIONS LIKE IRON AND CONSTANTAN PRODUCE MUCH HIGHER VOLTAGES. (THIS IS THE SEEBECK EFFECT.)



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

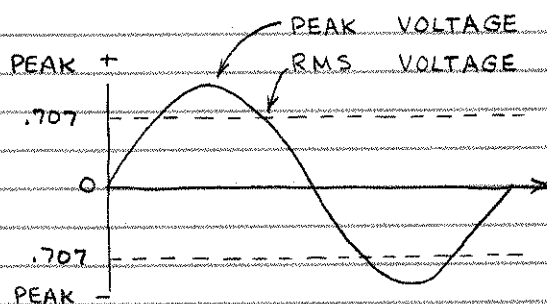
VOLTAGE OUTPUT

AC SINE WAVE

□ SINE WAVE MEASUREMENT -

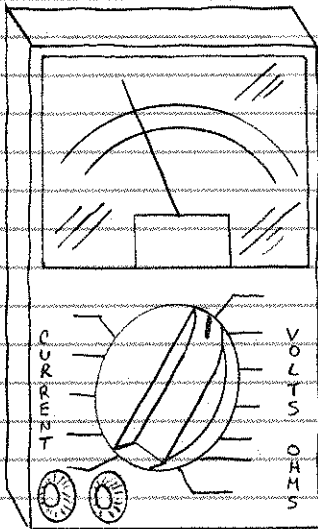
AC VOLTAGE IS USUALLY SPECIFIED AT A VALUE EQUAL TO THE DC VOLTAGE CAPABLE OF DOING THE SAME WORK. FOR A SINE WAVE THIS VALUE IS 0.707 TIMES THE PEAK VOLTAGE. IT'S

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 120×1.41 OR 169.2-VOLTS.

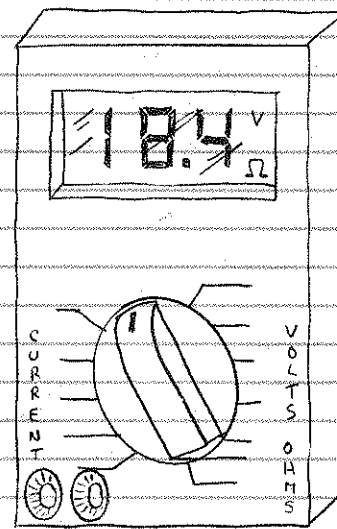


□ WHY AC IS USED - AC IS BETTER SUITED THAN DC FOR TRANSMISSION THROUGH LONG DISTANCE POWER LINES. A WIRE CARRYING AC WILL INDUCE A CURRENT IN A NEARBY WIRE. THIS IS THE PRINCIPLE BEHIND THE TRANSFORMER.

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.



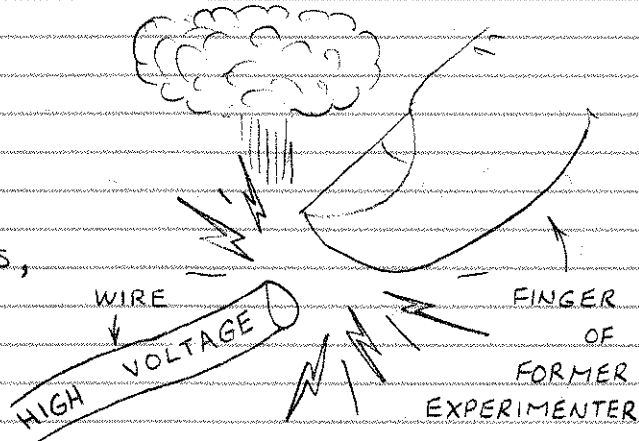
□ ANALOG MULTIMETER — LESS EXPENSIVE, SOMEWHAT LESS PRECISE THAN DIGITAL TYPES. BEST BY FAR FOR OBSERVING THE TREND OF A SLOWLY CHANGING VOLTAGE, CURRENT OR RESISTANCE.

□ 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

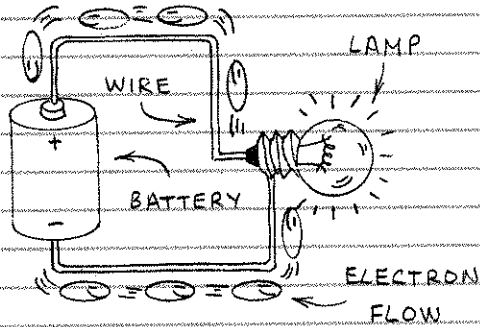
ELECTRICITY CAN KILL! IF YOU WANT TO BE AROUND LONG ENOUGH TO ENJOY EXPERIMENTING WITH ELECTRONICS, ALWAYS TREAT ELECTRICITY WITH THE RESPECT IT DESERVES. WE'LL LOOK AT SAFETY AGAIN LATER.



ELECTRICAL CIRCUITS

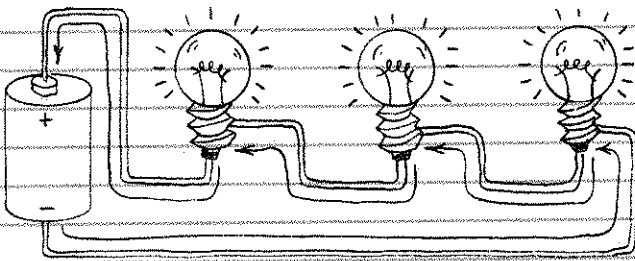
AN ELECTRICAL CIRCUIT IS ANY ARRANGEMENT THAT PERMITS AN ELECTRICAL CURRENT TO FLOW. A CIRCUIT CAN BE AS SIMPLE AS A BATTERY CONNECTED TO A LAMP OR AS COMPLICATED AS A DIGITAL COMPUTER.

□ A BASIC CIRCUIT —



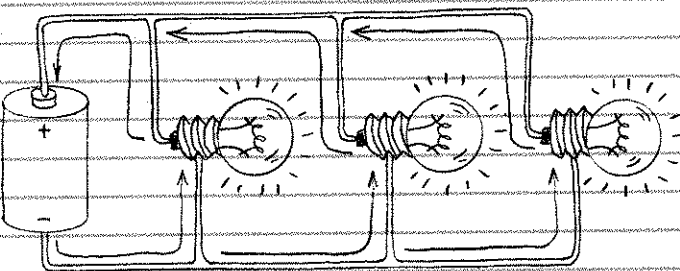
THIS BASIC CIRCUIT CONSISTS OF A SOURCE OF ELECTRICAL CURRENT (A BATTERY), A LAMP AND TWO CONNECTION WIRES. THE PART OF A CIRCUIT WHICH PERFORMS WORK IS CALLED THE LOAD. HERE THE LOAD IS THE LAMP. IN OTHER CIRCUITS THE LOAD CAN BE A MOTOR, A HEATING ELEMENT, AN ELECTROMAGNET, ETC.

□ A SERIES CIRCUIT — A CIRCUIT MAY INCLUDE MORE



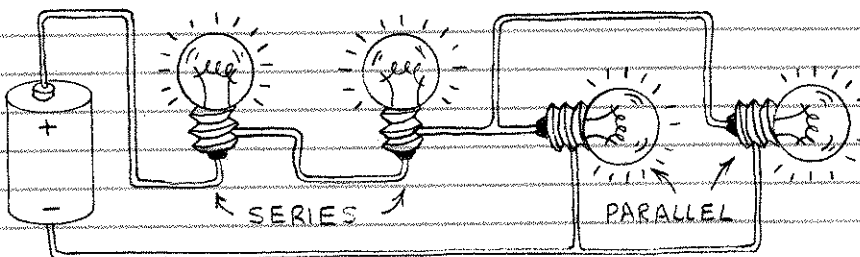
THAN ONE COMPONENT (SWITCH, LAMP, MOTOR, ETC.). A SERIES CIRCUIT IS FORMED WHEN CURRENT FLOWING THROUGH ONE COMPONENT FIRST FLOWS THROUGH ANOTHER. (ARROWS SHOW DIRECTION OF ELECTRON FLOW.)

□ A PARALLEL CIRCUIT —



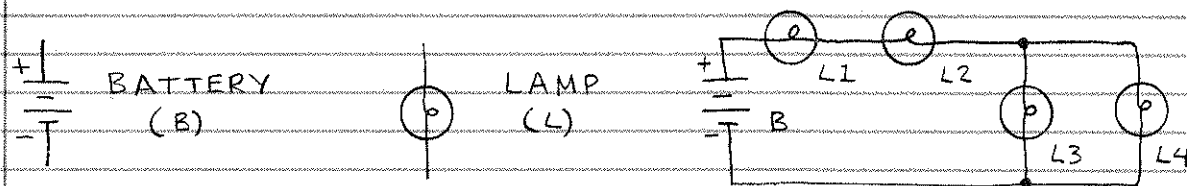
A PARALLEL CIRCUIT IS FORMED WHEN TWO OR MORE COMPONENTS ARE CONNECTED SO CURRENT CAN FLOW THROUGH ONE COMPONENT WITHOUT HAVING FIRST TO FLOW THROUGH ANOTHER.

□ 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.



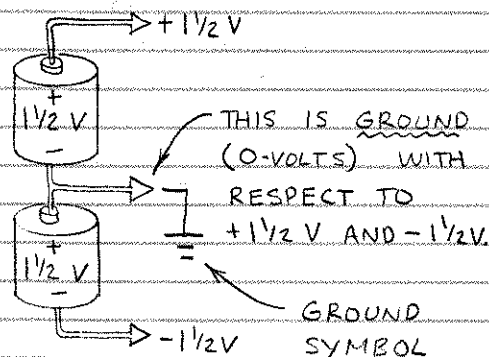
COMPONENT SYMBOLS

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.

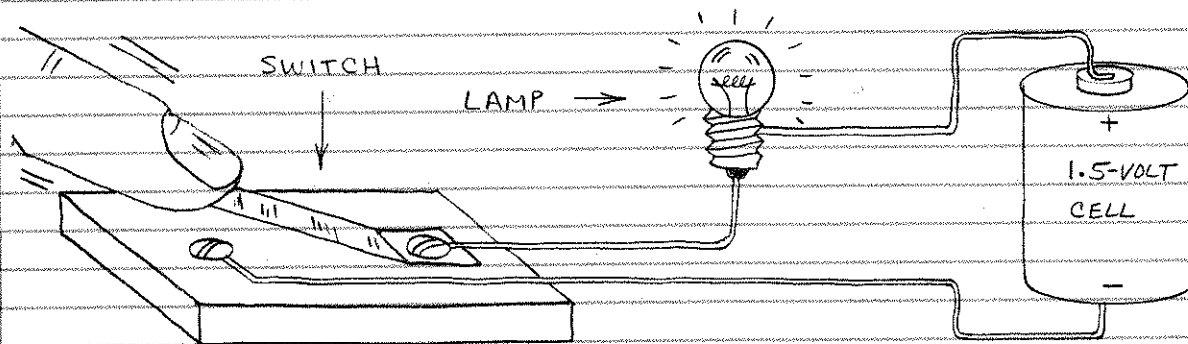
□ ELECTRICAL "GROUND" — ONE OF THE WIRES OF THE AC LINE IS CONNECTED TO EARTH BY A METAL ROD. METAL ENCLOSURES OF ELECTRICALLY POWERED DEVICES ARE CONNECTED TO THIS GROUND WIRE. THIS PREVENTS A SHOCK HAZARD SHOULD A NON-GROUNDED WIRE MAKE CONTACT WITH THE METAL ENCLOSURE. WITHOUT THE GROUND CONNECTION, 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.



PULSES, WAVES, SIGNALS AND NOISE

ELECTRONICS IS THE STUDY AND APPLICATION OF ELECTRONS, THEIR BEHAVIOUR AND THEIR EFFECTS. THE SIMPLEST APPLICATIONS FOR ELECTRONS ARE STRAIGHTFORWARD AC AND DC CIRCUITS IN WHICH A CURRENT IS USED TO POWER LAMPS, ELECTROMAGNETS, MOTORS, SOLENOIDS AND SIMILAR DEVICES. WHAT TAKES ELECTRONICS FAR BEYOND THESE BASIC APPLICATIONS IS THE EASE WITH WHICH STREAMS OF ELECTRONS CAN BE CONTROLLED AND MANIPULATED.



THIS SIMPLE CIRCUIT IS REALLY MORE USEFUL THAN IT FIRST APPEARS BECAUSE IT CAN SEND INFORMATION BY CONVERTING A PLANNED SEQUENCE OF SWITCH CLOSURES INTO FLASHES OF LIGHT.



THE FLASHES OF THE LAMP CAN BE REPRESENTED BY A DIAGRAM LIKE THIS...



PATTERNS OF FLASHES OR PULSES LIKE THESE CAN REPRESENT COMPLEX INFORMATION LIKE SPEECH. OR SPEECH CAN BE TRANSFORMED INTO PROPORTIONAL VARIATIONS IN THE BRIGHTNESS OF A LAMP. HERE'S A SIMPLE WAY TO SEND VOICE OVER A BEAM OF REFLECTED LIGHT:

