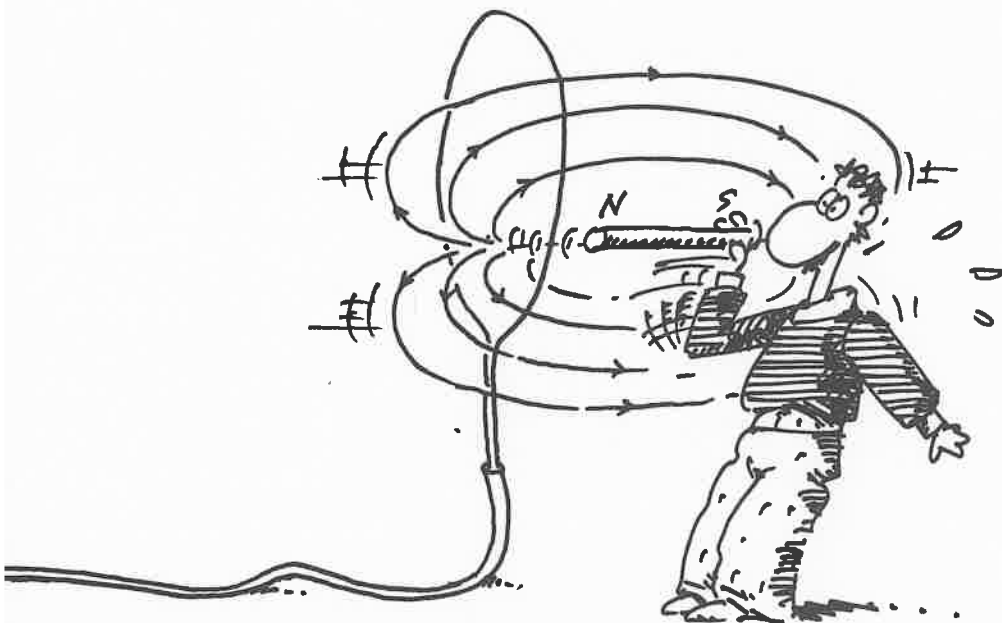


• PART TWO •
ELECTRICITY
AND
MAGNETISM

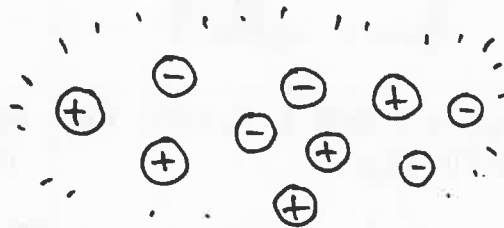


* CHAPTER 12 * CHARGE

WE NOW TURN FROM MECHANICS TO ELECTRICITY AND MAGNETISM. IN MECHANICS WE USED THE BASIC PROPERTY OF MATTER CALLED **MASS**. IN ELECTRICITY, THE BASIC CONCEPT IS **CHARGE**.



MECHANICAL
CONCEPT



ELECTRICAL CONCEPT

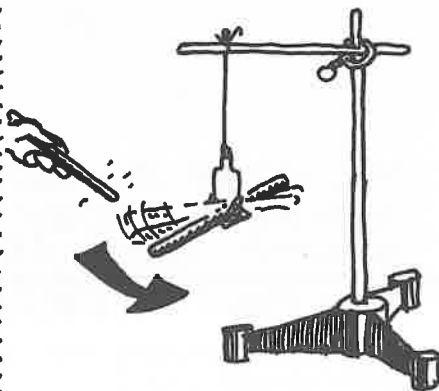
NOTICE THAT MECHANICS NEVER TOLD US WHAT MASS "REALLY IS," BUT ONLY HOW IT BEHAVES. IN THE SAME WAY, CLASSICAL E&M TELLS US HOW CHARGE BEHAVES, BUT NOT WHAT IT IS.



IT IS EASY TO PRODUCE A LITTLE CHARGE — JUST RUN A RUBBER COMB THROUGH YOUR HAIR, OR RUB A RUBBER ROD WITH ANIMAL FUR.



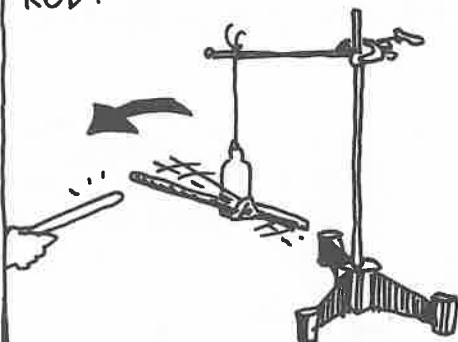
PLACE THE CHARGED ROD IN A HANGING STIRRUP AND BRING ANOTHER, SIMILARLY CHARGED ROD NEAR — THEY **REPEL**.



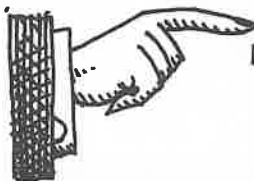
BUT IF I RUB A PLASTIC ROD WITH SILK...



IT ATTRACTS THE RUBBER ROD!



FROM EXPERIMENTS LIKE THESE WE LEARN THAT



THERE ARE **TWO** KINDS OF CHARGE...

AND THAT LIKE CHARGES REPEL, AND UNLIKE CHARGES ATTRACT!!

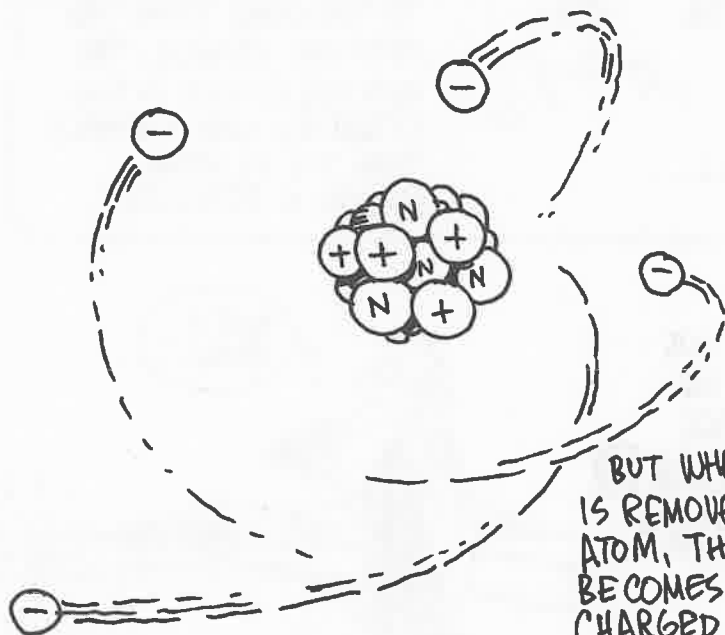




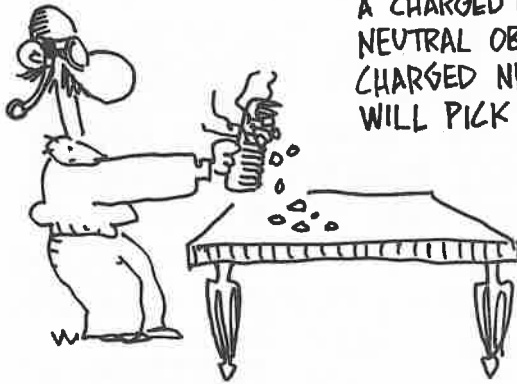
BENJAMIN FRANKLIN

(1706-1790) NAMED THE TWO KINDS OF CHARGES **POSITIVE** AND **NEGATIVE**. WE NOW KNOW THAT ALL MATTER IS MADE OF ATOMS, WHICH ARE COMPOSED OF NEGATIVELY CHARGED **ELECTRONS**, WHIRLING AROUND A NUCLEUS OF POSITIVELY CHARGED **PROTONS**, AND **NEUTRONS**, WHICH HAVE NO CHARGE.

ELECTRONS AND PROTONS HAVE EQUAL AND OPPOSITE CHARGES. NORMAL ATOMS HAVE EXACTLY ENOUGH ELECTRONS TO BALANCE THE PROTONS IN THE NUCLEUS, MAKING THE ATOM OVERALL NEUTRAL.



BUT WHEN AN ELECTRON IS REMOVED FROM AN ATOM, THE ATOM BECOMES A POSITIVELY CHARGED **ION**.



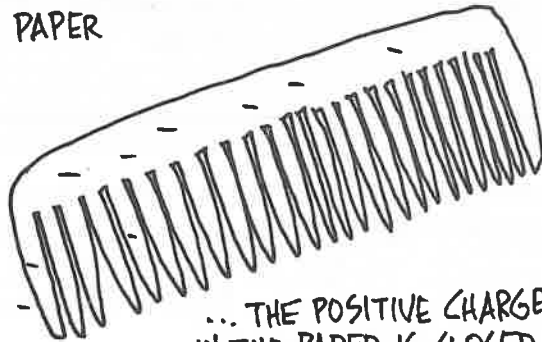
A CHARGED OBJECT WILL ALSO ATTRACT NEUTRAL OBJECTS. THIS RUBBER COMB, CHARGED NEGATIVELY BY RINGO'S HAIR, WILL PICK UP BITS OF PAPER.

IT DOES SO BECAUSE THE PAPER BECOMES ELECTRICALLY

POLARIZED:

THE NEGATIVE COMB REPELS ELECTRONS IN THE PAPER AND ATTRACTS THE POSITIVE NUCLEI OF THE ATOMS IN THE PAPER.

THERE IS A CHARGE SHIFT IN THE PAPER! EVEN THOUGH IT IS NEUTRAL OVERALL ...

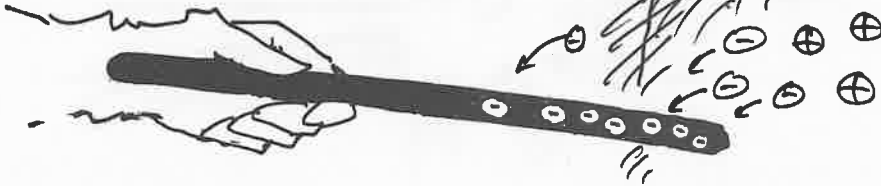


... THE POSITIVE CHARGE IN THE PAPER IS CLOSER TO THE COMB THAN THE NEGATIVE CHARGE. THE POSITIVE CHARGE IS THEN ATTRACTED MORE STRONGLY THAN THE NEGATIVE CHARGE IS REPELLED!

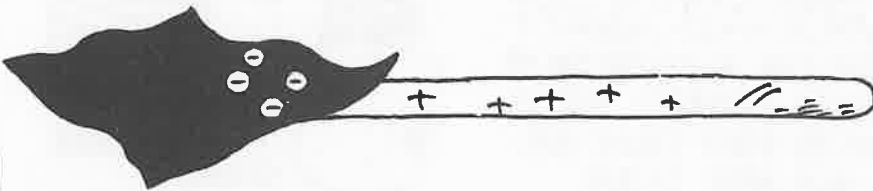
FROM SUCH OBSERVATIONS, WE DEDUCE THAT THE ELECTRICAL FORCE **GROWS WEAKER WITH DISTANCE.**



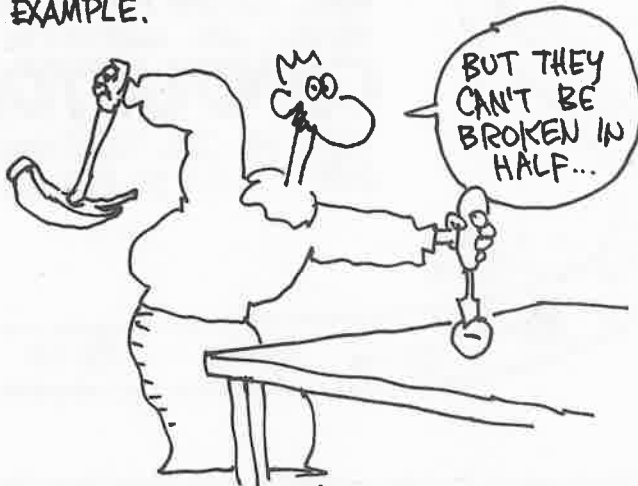
WHEN YOU RUB THE RUBBER ROD WITH FUR, SOME ELECTRONS ARE RUBBED OFF THE FUR AND ONTO THE RUBBER, SO THE RUBBER ROD ACQUIRES A NET NEGATIVE CHARGE (LEAVING THE FUR POSITIVE).

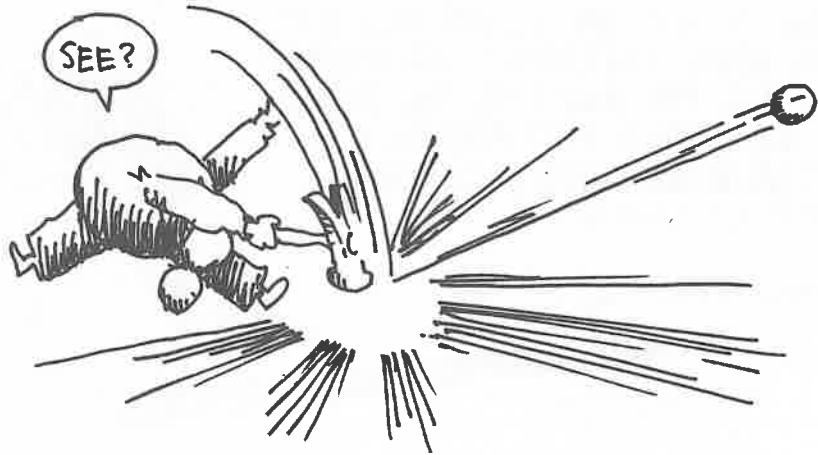


SIMILARLY, SILK RUBS ELECTRONS OFF THE PLASTIC, LEAVING THE PLASTIC WITH A NET POSITIVE CHARGE.



ELECTRONS ARE ELEMENTARY UNITS OF CHARGE, AND ARE EASILY TRANSFERRED FROM ONE OBJECT TO ANOTHER. THEY MAY ALSO BE PASSED ALONG THE SAME OBJECT - LIKE A COPPER WIRE, FOR EXAMPLE.

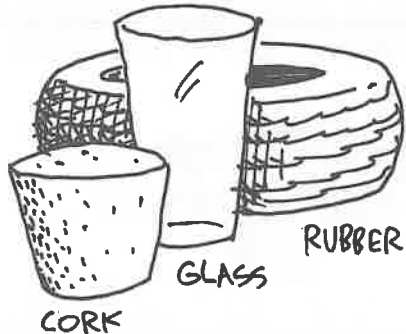




MATERIALS LIKE RUBBER, GLASS,
AND PLASTIC ARE ELECTRICAL

INSULATORS

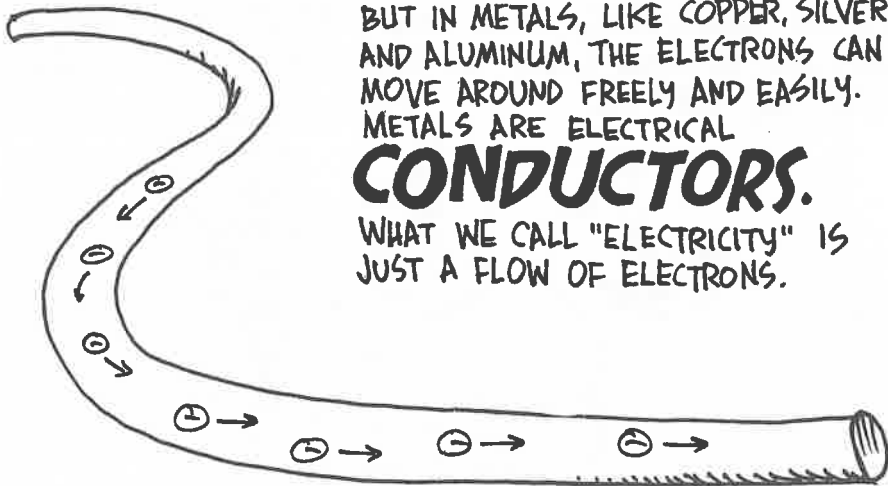
CHARGE CAN BE RUBBED ON OR
OFF THEIR SURFACES, BUT IT
TENDS TO STICK THERE AND
WILL NOT MOVE EASILY
THROUGH THE MATERIALS.



BUT IN METALS, LIKE COPPER, SILVER,
AND ALUMINUM, THE ELECTRONS CAN
MOVE AROUND FREELY AND EASILY.
METALS ARE ELECTRICAL

CONDUCTORS.

WHAT WE CALL "ELECTRICITY" IS
JUST A FLOW OF ELECTRONS.





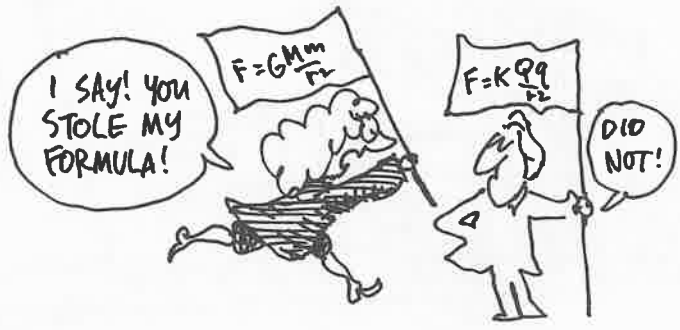
CAREFUL MEASUREMENTS BY CHARLES COULOMB (1736-1806) ESTABLISHED THAT THE ELECTRIC FORCE DECREASES WITH THE SQUARE OF THE DISTANCE, LIKE GRAVITY. COULOMB'S LAW FOR ELECTROSTATIC* FORCES IS VERY MUCH LIKE NEWTON'S LAW OF GRAVITY:

$$F = k \frac{Qq}{r^2}$$

*ELECTROSTATIC MEANS THAT THE CHARGES ARE STATIONARY.

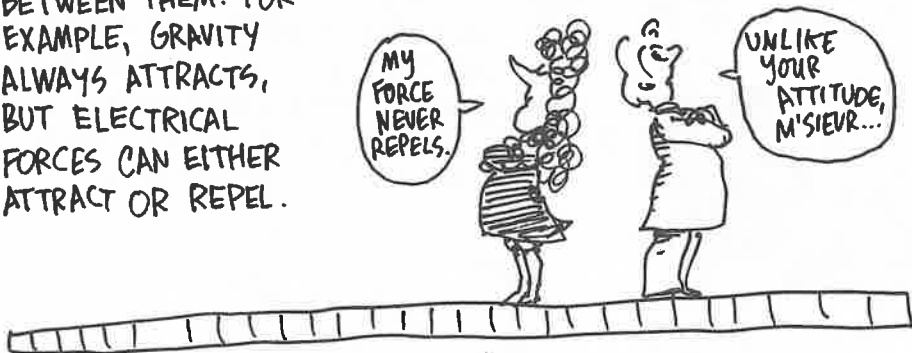
IN COULOMB'S EQUATION, Q AND q ARE THE VALUES OF THE CHARGES, r IS THE DISTANCE BETWEEN THEM, AND K IS A CONSTANT, LIKE G FOR GRAVITY. IN STANDARD UNITS, $k = 9 \times 10^9$.

THE UNIT OF CHARGE IS THE COULOMB. A SINGLE ELECTRON HAS A CHARGE OF $-e = 1.6 \times 10^{-19}$ COULOMBS.

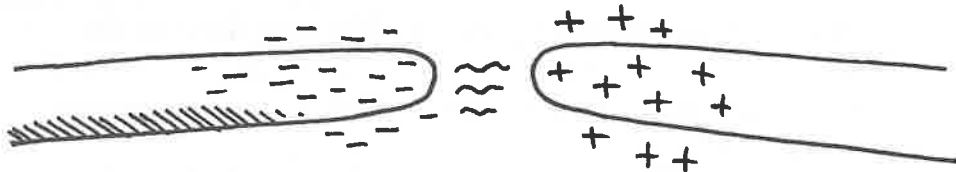


JUST HOW SIMILAR ARE THE GRAVITATIONAL AND ELECTROSTATIC FORCES?

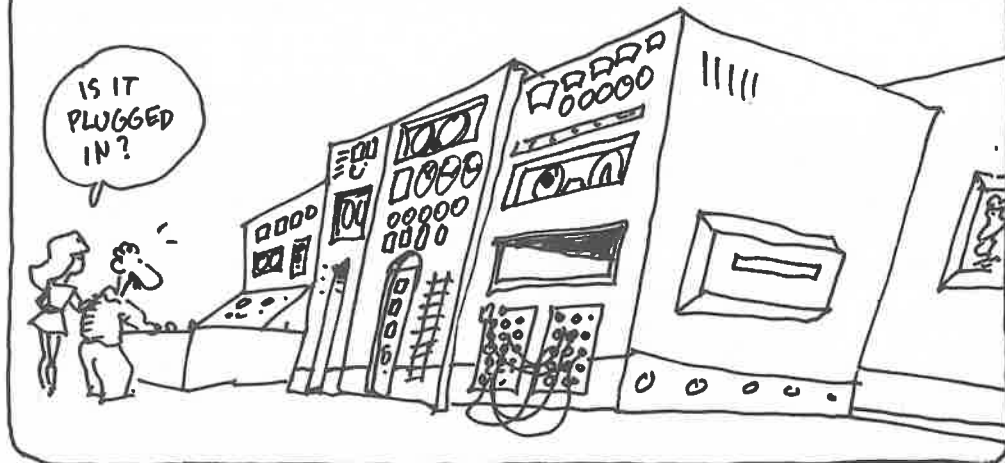
ALTHOUGH THE LAW OF ELECTROSTATIC FORCES SEEMS VERY SIMILAR TO THE LAW OF GRAVITY, THERE ARE MAJOR DIFFERENCES BETWEEN THEM. FOR EXAMPLE, GRAVITY ALWAYS ATTRACTS, BUT ELECTRICAL FORCES CAN EITHER ATTRACT OR REPEL.



ALSO, ELECTRICAL FORCES ARE VASTLY STRONGER THAN GRAVITATIONAL FORCES. IF A (MERE!) HUNDRED BILLION ELECTRONS WERE MOVED FROM A PLASTIC ROD TO A RUBBER ONE, THERE IS A PERCEPTIBLE ATTRACTION BETWEEN THEM.



BUT EVEN WITH ALL 10^{24} ($= 10^{15}$ BILLION) ATOMS IN THE ROD PULLING GRAVITATIONALLY, THE MOST SENSITIVE INSTRUMENTS WOULD HAVE TROUBLE DETECTING IT!

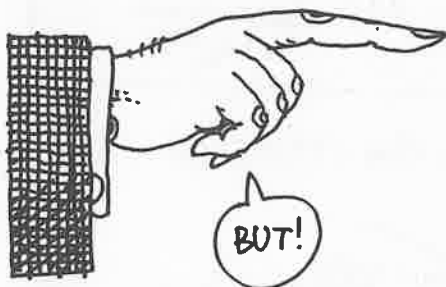
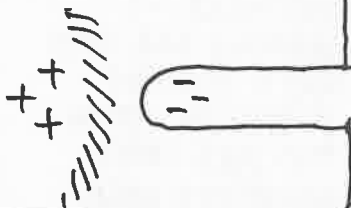




CHEW ON THIS!

CHARGE IS CONSERVED — THE NET CHARGE, THE SUM OF THE NEGATIVE AND POSITIVE CHARGES IN AN ISOLATED SYSTEM CANNOT CHANGE.

(WHEN THE NEUTRAL RUBBER WAS CHARGED BY THE ANIMAL FUR, THE POSITIVE CHARGE ON THE FUR MATCHES THE NEGATIVE CHARGE ON THE RUBBER.)

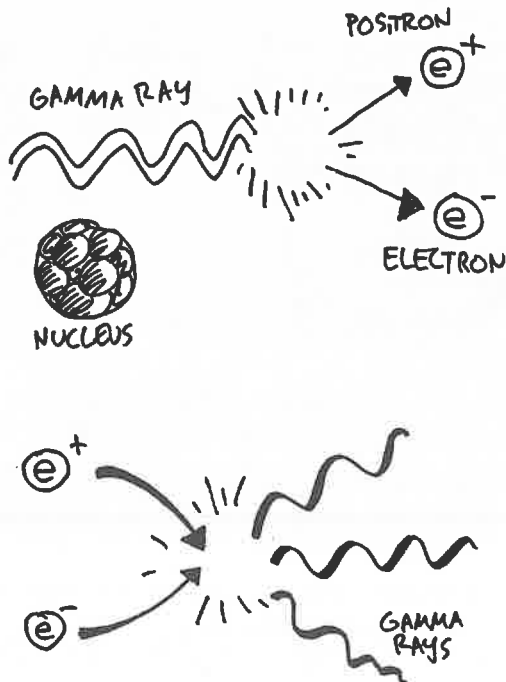


IT IS POSSIBLE TO
CREATE PAIRS OF
CHARGES FROM
NOTHING

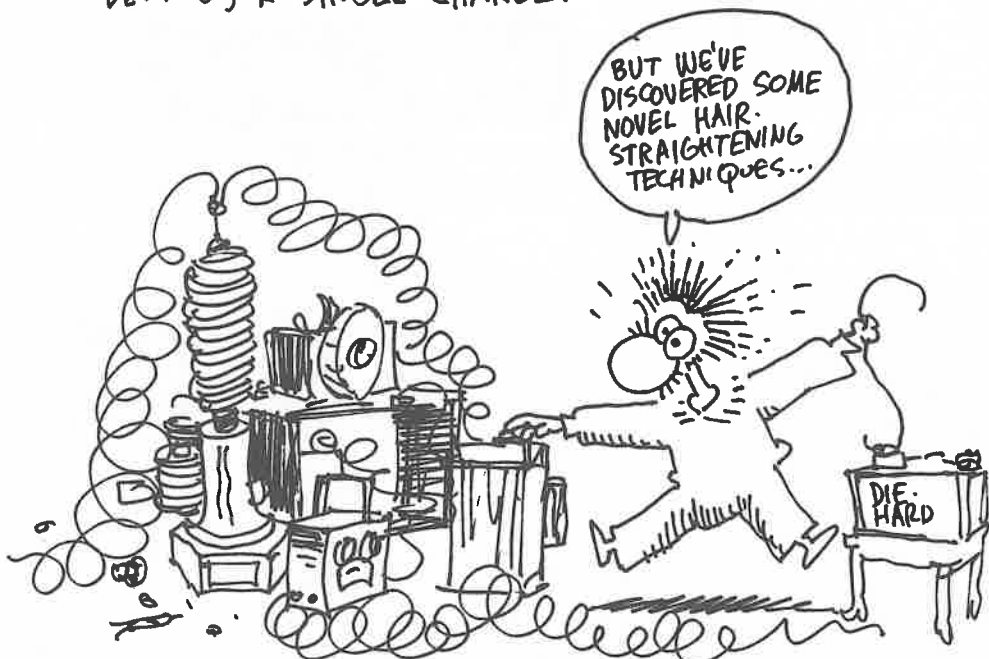


NOTHING
BUT
ENERGY,
THAT IS!

THIS IS DONE BY
A **GAMMA RAY**,
A VERY HIGH-ENERGY
PARTICLE OF LIGHT.
WHEN A GAMMA RAY
PASSES NEAR AN
ATOMIC NUCLEUS, IT
MAY CREATE TWO
PARTICLES — A
NEGATIVE ELECTRON
AND A POSITIVE
POSITRON. THESE
TWO MAY LATER
ANNIHILATE EACH
OTHER, PRODUCING
MORE GAMMA
RAYS.



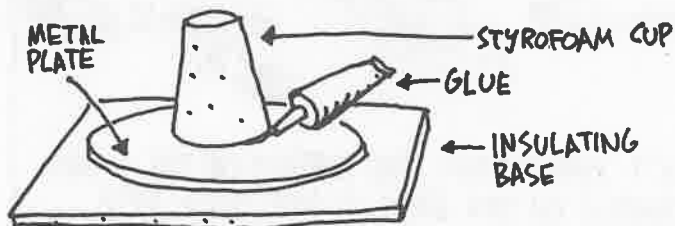
BUT NO KNOWN PHYSICAL PROCESS CAN CREATE OR DESTROY A SINGLE CHARGE!



A PIECE OF ELECTROSTATIC APPARATUS YOU CAN MAKE FOR YOURSELF IS AN

ELECTROPHORUS.

INVENTED
BY VOLTA
IN 1775!

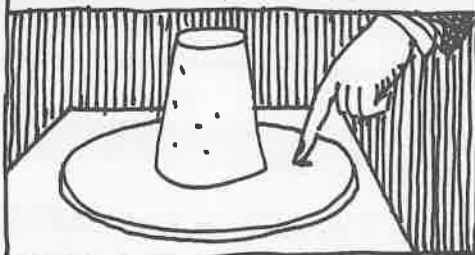


YOU'LL NEED A PLASTIC PLATE FOR THE BASE AND A METAL PIE PLATE WITH AN INSULATING HANDLE, SAY A STYROFOAM CUP, GLUED TO IT.

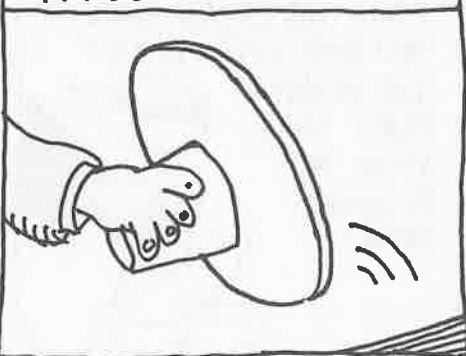
RUB THE BASE WITH SILK, FUR, OR WOOL, TO CHARGE IT.



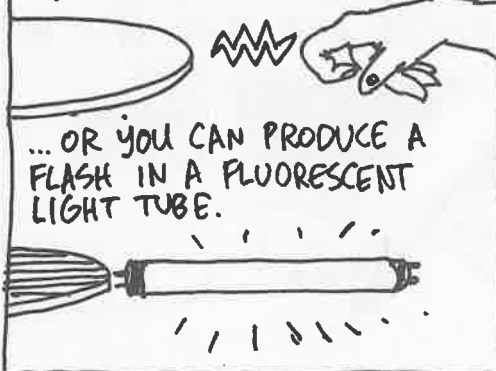
NOW PLACE THE METAL PLATE ON THE BASE, AND TOUCH THE PLATE WITH YOUR FINGER.



LIFT THE PLATE OFF THE BASE BY THE INSULATING HANDLE.

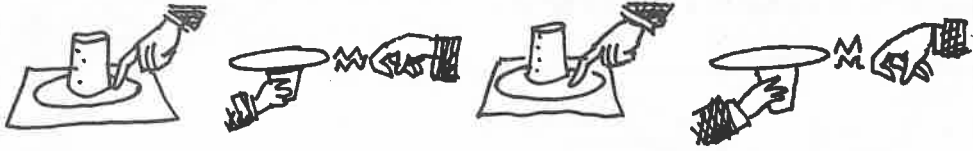


NOW YOU CAN DRAW A SPARK OFF THE PLATE WITH YOUR KNUCKLE...



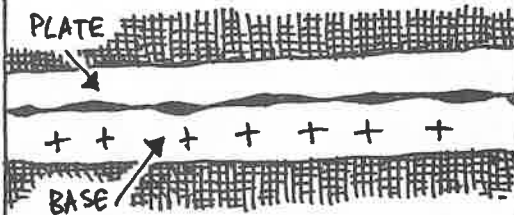
... OR YOU CAN PRODUCE A FLASH IN A FLUORESCENT LIGHT TUBE.

AN INTERESTING FEATURE OF THIS EXPERIMENT IS THAT YOU CAN RECHARGE THE PLATE BY TOUCHING IT WITH YOUR FINGER REPEATEDLY, WITHOUT FURTHER RUBBING OF THE BASE.

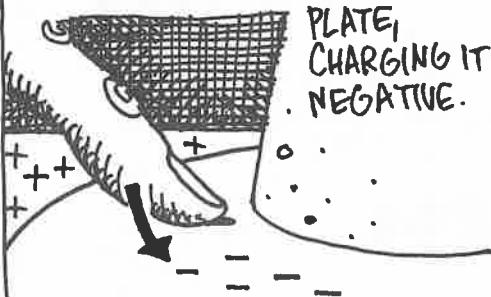


HOW DOES THIS WORK? WHERE DOES THE ENERGY OF THE SPARK COME FROM IF THE CHARGE ON THE BASE IS NOT USED UP?

THE BASE IS CHARGED POSITIVE BY RUBBING. WHEN THE PLATE IS PLACED ON THE BASE, IT ACTUALLY TOUCHES IT IN ONLY A FEW PLACES:



SINCE THE BASE IS AN INSULATOR, VERY LITTLE CHARGE FLOWS. BUT WHEN YOU TOUCH THE METAL, ELECTRONS IN YOUR BODY, ATTRACTED BY THE POSITIVE BASE, FLOW ONTO THE



YOUR BODY SERVES AS AN **ELECTRICAL GROUND**, A RESERVOIR OF POSITIVE AND NEGATIVE CHARGES. SINCE THE CHARGE ON THE PLATE COMES FROM YOU, THE EXPERIMENT CAN BE REPEATED INDEFINITELY.



AND WHERE DOES THE SPARK'S ENERGY COME FROM? IT COMES FROM THE EXTRA FORCE YOU MUST EXERT TO LIFT THE NEGATIVE PLATE AWAY FROM THE POSITIVE BASE!

