Name ________________________ Partner(s) ______________________________

Lab Date & Time _________________________ Instructor_____________________

Laboratory 1:

Electric Charge & Force

Objectives

- ☐ Separate negative electric charge from positive charge.
- ☐ Observe as unbalanced charges push or pull other electric charges.
- ☐ Verify that the electric force strength increases at smaller distances.
- ☐ Deduce that the Force direction depends on the signs of both charges, as opposite signs attract but like signs repel.
- ☐ Notice that an isolated charge always attracts any dipole it induces.
- ☐ Infer that electric charge can move thru conductive matter, but not thru insulators.

Apparatus

☐ Transparent tape

☐ Hand-held Van der Graaff generator

☐ Pivoting-needle electroscope with disk electrode on top

☐ Empty aluminum can

☐ flat metal pates held vertically parallel on an insulating (plastic) stand

☐ Styrofoam “pith” ball with metal coating on string, to hang between plate centers

Pre-Lab Thoughts

Please respond to the following statements, to evaluate them with your background before doing the lab, or even reading the lab book or a lecture text-book.

1. Static electricity is charge is often created by friction or heat.

2. A positively charged object probably had protons added to it.

3. Only positively charged objects can attract other charged objects.

4. The electric force is independent of the distance between the charged objects.

Background

This laboratory will investigate static electricity. “Static” means the electric charge was separated, and the macroscopic electric situation changes only “slowly”. In 1269, *electric* meant “acting like rubbed amber”, attracting nearby hay-chaff. In 1600 William Gilbert found that metals, if touched by rubbed amber, can transmit that electric property as if it was a fluid. In 1750 Ben Franklin found that there were two fluids, which we call *positive* and *negative*. These can be separated temporarily, but will *neutralize* if allowed to recombine. These “fluids” are billions of tiny particles that have a property called *electric charge*. Electric charge is a conserved quantity, symbol Q or q. Charge quantity is an intrinsic property of each sub-atomic particle. But on a macroscopic (millimeter) scale, charge acts as like a manipulable condition, since the tiny electrons that move so easily can change a region’s net charge without noticeably changing its mass or appearance.

Every atom has a nucleus at its center, holding a specific number (symbol Z) of protons, each having charge $+1e$ (e is short for *elementary charge*). Most nuclei contain a number (symbol N) of neutrons, each having 0 net (total) charge. Electric charge is an additive scalar property, so every nucleus has charge $Z(+e) + N(0e) = Ze$ (positive).

An electric charge Q_+ pulls opposite-sign charges q_- toward itself, but pushes like-sign charges q_+ away. Electrons, each with charge $-1e$, are attracted to the interior (+) charge, so accumulate around it. These form layers (lab 12), some with structure details. Inner electron shells *screen* all outer charges from feeling the full nuclear charge *Ze* (outer clouds deform to screen the inner ones from external charges or magnets). Electrons collect until the Y of them make the whole atom become neutral ($Ze - Ye = 0$).

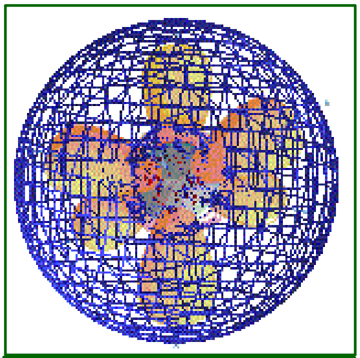

Fig.1 a sodium atom

Figure 1 shows a sodium atom cartoon: 10 of its 11 electrons are deep inside the 1 outer-most electron (blue shell #3) – the 6 yellow lobes are shell #2 clouds. In sodium metal (Fig.2), those lobes fasten the ion (interior items, charge +*e*) to others in the metal lattice. The outermost (shell #3) electron clouds spread over about 20 (+) ion core neighbors each way. Being so thin, these *conduction* electrons can be pulled thru the ion core lattice (like wind thru trees). Ions, and hence all things, always have an integer number n of elementary charges:

$$\Sigma Q = n\, e \qquad \ldots \qquad (1) \qquad .$$

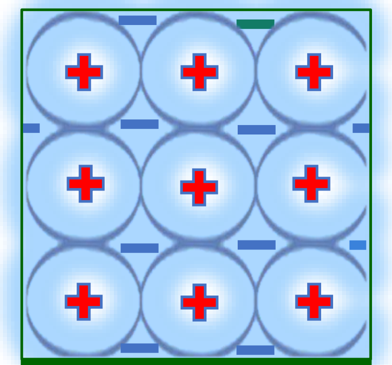

Fig.2 sodium metal

The electric Force applied to an object charge q_o is weak far from the subject charge Q_s, since the Electric Field $\vec{E}$ carried by that source is spread over a large Area there.

$$\vec{F} = q_o \vec{E} = q_o \frac{k_c Q_S\, \hat{r}}{r^2} \qquad \ldots \qquad (2) \qquad .$$

Here $\hat{r}$ (length 1) is away from positive Q_s (unlike gravity); k_c is Coulomb’s constant, whose value in lab-scale units is $k_c \approx 9{\times}10^9 \frac{Nm^2}{C^2}$. Electric measurements are so modern that there are no Imperial units. The Force which pulls an individual electron is microscopically weak, and weakens rapidly with distance, but often there are billions of electrons being pulled – so the electric Force can become appreciable.

The outermost electron can be removed from an atom, leaving a positive ion, by giving it enough Energy (called that atom's ionization Energy). Atoms for each chemical element need a distinct ionization Energy; with their slightly different sizes, they hold their outermost electron to the (positive) ion core more firmly or less so. This is related to electronegativity, describing which nonmetals can “steal” an electron from which metals. When a Na atom approaches a Cl atom, the Cl atom steals the Na atom's outer electron: $Na + Cl \Rightarrow Na^+ + Cl^-$. Atoms that have lost or gained some electrons are called *ions*; each ion now electrically attracts the other (oppositely-charged) ion. Complicated materials also give away (or take) electrons from a surface, as they separate after contact.

Their propensity to lose or gain electrons is found experimentally; surfaces that touch are sorted into a *triboelectric* order, those that become positive to those becoming negative, relative to their neighbors in the list. The order is approximate: Temperature, adhesion, and trace impurities (especially water) greatly alter the local surface's electric behavior.

+positive, oily skin, asbestos, dry skin, glass, nylon, fur/wool, silk, paper, cotton, silver, amber, acrylic, epoxies, PET, cellulose, PVC, latex, silicon, teflon, –negative

Fig.3 approximate triboelectric series

Outer-most electrons in many materials stay in one place, bonding two atoms together; most hydrocarbons, salts, and oxides are *insulators*. An external charge can pull (or push) those electrons only a small distance (say, ¼ of an atom) from their bond centers, but all the molecules (10^{22} !) are polarized, so the accumulated attraction can be noticeable. Charged amber must polarize the insulating hay, before it attracts that material.

If electrons in an insulator are pulled too hard, some can be pulled off their parent atom (now an ion); these travel very fast, knocking more electrons off molecules along their path, forming an electric discharge spark. (Familiar from lightning through the air.)

Some materials allow an electron (per atom) to move thru their bulk among the (positive) ion cores; most such *conductors* are metals. If a conductor holds excess charge, its mobile *conduction electrons* are pulled by the *Electric Field* to spread that charge on the conductor's outer surface. [We'll quantify this Electric Field in Lab 2.]

Because electrons repel each other, a surface covered with excess electrons that contacts (or gets very close to) another surface will allow some electrons to move onto the other surface. A surface deficient in electrons can pull some electrons onto it from a neutral surface, if the surfaces get close enough. Any process that transfers electrons from one to the other is described as "charging by contact" even if the surfaces don't actually touch.

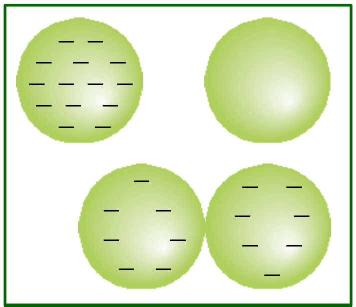

Fig. 4 charge transfer

A big positive external charge near a neutral conductor (aluminum can) will pull some mobile electrons (2 or 3 electrons per trillion atoms) all the way to the edge of the metal (¼ billion atom-lengths), leaving behind their positive ion cores. So the attracted charge is close to that external charge, but the same amount of repelled charge is far from it (in a weaker Electric Field). This charge separation only remains while the external charge is nearby – such charge separations are said to be *induced*. Induced charge separations can be made permanent, if the conductor is made of two parts that can be separated.

A. Adhesive Tape as an Insulating Electrode & Force Gauge

1. Single Tape from Table with Single Tape from Table

Clean your lab table surface with a paper towel, be sure it is dry.

Pull 2 strips of adhesive tape 40-80 mm long from a roll; fold one end of each under, to make a 5-10 mm long non-sticky handle.

Stick them both to the table – rub them so they both stick well. Your finger should lose electrons to the tape's smooth top (look back on the previous page, to see the triboelectric order for plastic & skin).

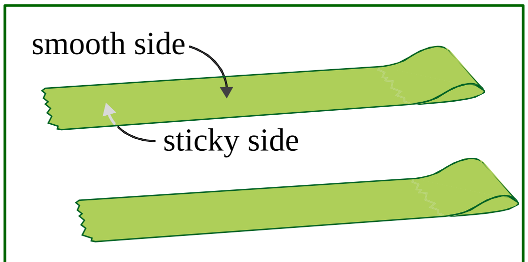

Fig. 5 two single tape strips

Peel the tapes off the table, hold them near each other, but not touching, smooth side toward smooth side.

Don't let a tape curl back & touch your hand – stick it back on the table if it does. (why would the tape "want" to touch your hand?)

Do the tapes flex, as if they <u>attract</u> each other, or as if they <u>repel</u> each other?

With the same preparation for each tape, (same adhesive, table surface, finger) both tapes should have brought negative charges from the table and your finger.

Did you verify that those like-sign charges repel? ______
try it again, with fresh tape, if they did not repel.

The table surface should have been left with { negative | positive | zero } charge.

Wipe those charges from the table-top with your hand (a pretty good conductor.

2. Check Tape Forces for all Orientations

Verify that electric charge is a scalar (not a vector) property by trying

smooth side to smooth side { attract | repel }

and sticky side to smooth side { attract | repel }

tapes parallel with lengths along each other { attract | repel }

tapes parallel with lengths opposite each other { attract | repel }

tapes oriented with lengths perpendicular each other { attract | repel }.

3. Two-Tape stack from Table with Single Tape from Table

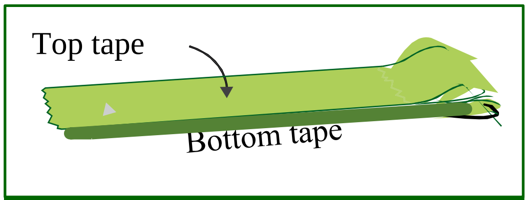

Fig. 6 a 2-tape stack

Rub a long “bottom” tape onto a clean table area and then rub a slightly shorter “top” tape onto the bottom tape … also rub another single tape onto the table.

Pull the 2-tape stack off the table as one piece; check it against the **single tape**. they { attract | repel }

Now (in the air) **peel top** tape **from bottom** tape, check each tape against each other:

top tape { attracts | repels } single tape

bottom tape { attracts | repels } single tape

top tape { attracts | repels } bottom tape

If like-sign charges repel, which tape’s charge is UNlike the single tape’s charge?

{ bottom | top | both | neither } .

4. Bottom with Bottom and Top with Top

Make 2 fresh 2-tape stacks – check if one unlike and the other unlike are alike:

Pull both stacks off the table , then peel them apart in the air.

one bottom tape { attracts | repels } the other bottom tape

one top tape { attracts | repels } the other top tape

verify that one bottom tape { attracts | repels } the other’s top tape.

B. Hand-held Van der Graaff Generator with Electroscope

1. Battery Power is only to run the belt

Figure 5 shows the inner workings of a Van de Graaff generator. A small 6V motor drives a plastic pulley, which pulls electrons from the latex belt. The latex belt pulls electrons from the brass pulley at the housing’s top end. Those electrons are replaced by electrons from the slightly-conductive cardboard wand tip. See the triboelectric sequence at left.

Thus, the inside surface of the rubber belt becomes negatively charged. By induction, the outside of the belt becomes positively charged. A conducting brush, referred to as the charge-spray-comb, at the base of the pulley drains the negative charges on the outside of the belt to ground. At the top of a belt is a metal pulley and a charge-spray comb which is connected to the "collector," Most larger Van der Graaff generators have their plastic pulleys on top, so their domes are negative.

But the charge separation happens at the pulleys : the rubber belt pulls electrons from the top (glass/brass) pulley, bottom (PVC) pulley collects them from the belt. So the wand top end becomes { negative | neutral | positive } .

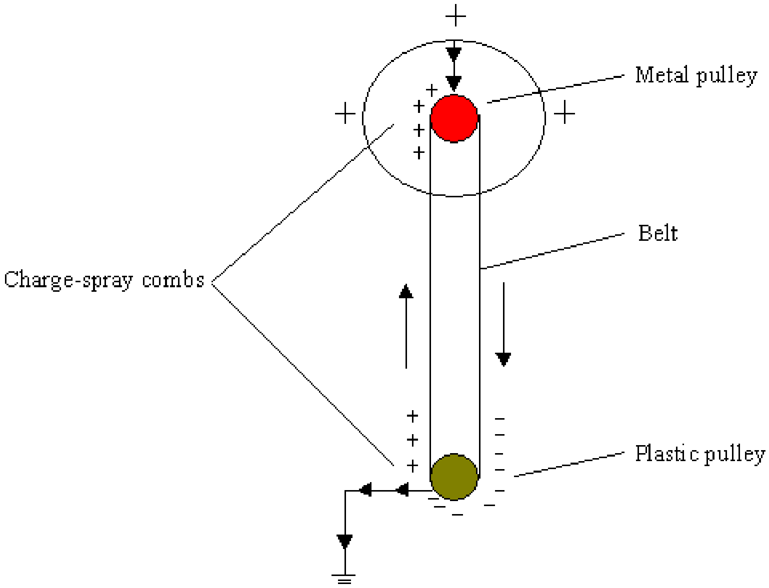

Figure 1: Internal construction of Van de Graaff Generator

Where do those electrons eventually go? How can they get to the ground (Earth)?

Clean a spot on the able, prepare a final single adhesive tape … prediction first:

if the single tape is negative, the wand top will { attract | repel } the tape.

Okay, check the sign on the wand top end against the single tape.

they { attract | repel } .

2. Charging Electroscope by Contact with its Disk Electrode

Examine the neutral electroscope, as shown in Figure 6. Trace the conductive path from the top disk, thru the big ring, to the hanging post. The ring is metal, conductive to isolate the needle from effects of charges outside it. See that the needle tube rotates easily on its pin bearing, so it hangs straight down when there is no charge inside the ring (what does that imply?).

Touch the (running) VdG's wand to the electroscope's disk. After the needle angle stabilizes, remove the VdG wand. What happens to the needle? What θ?

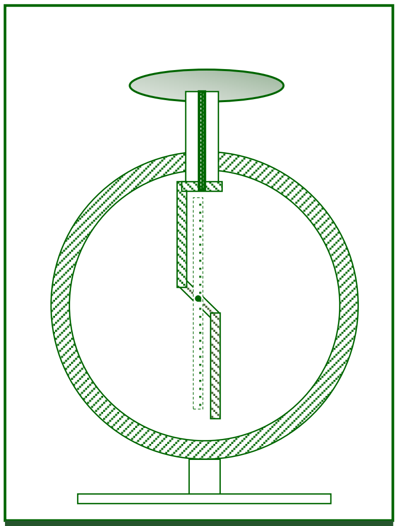

Fig. 6 electroscope

Draw the needle at its charged orientation. Draw charges (+/–) on the needle, and any other charged region, to show how the needle stays at a non-zero angle.
Where are the charges that apply Force to the needle's charges?

3. Charging Neutral Electroscope by Induction – No Contact Allowed!

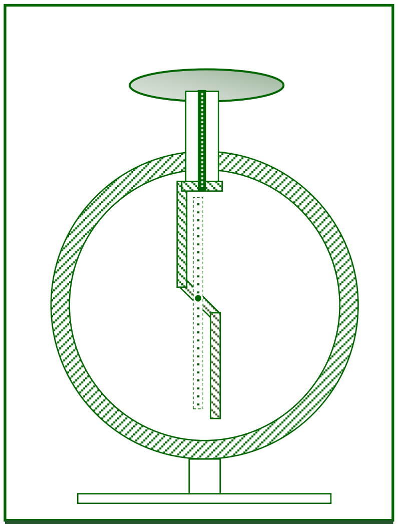

Fig. 7 electroscope

A spark path thru an insulating solid is usually scorched, and often has become permanently conductive.

4. Van der Graaff Separates Charge in a metal Can

Hold the running VdG horizontally beside the neutral aluminum can **Not too close, or it might spark!** (front view shown in Figure 8). Decrease the distance to the can slowly, until the can starts to accelerate – then try to keep that same distance!.

Carefully draw (+ / –) signs to show where the charges are then Explain in Words why the attraction Force is stronger than the repulsion Force. [reminder – the can was neutral, and no sparks jumped to it.)

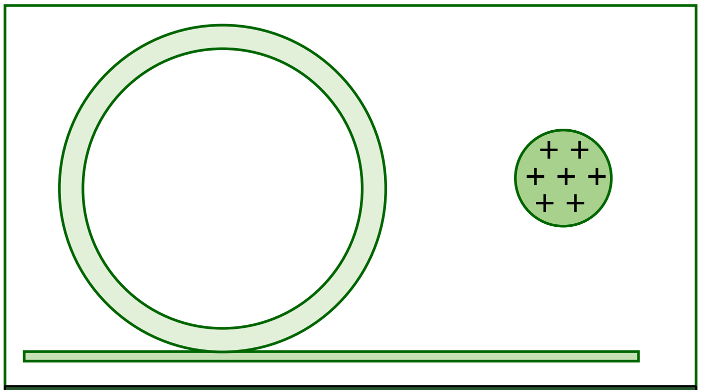

Fig. 8 aluminum can beside Van der Graff

The VdG pulled some conduction electrons from the can's far side to its near side, leaving ion cores behind. The VdG's charge *induced* this charge separation.
If the can accelerated at ½ $^{m}/_{s^2}$, some–60 nanoCoulomb moved across its diameter.

The can's charges were { attracted | repelled } by the VdG charge.

5. (Optional) Separate Charge in a Plastic Bottle

A plastic bottle has about the same mass as the aluminum can, but the plastic is an insulator … so has no conduction electrons. This means that all plastic molecules would experience the VdG's Electric Field, so all would polarize. [In contrast, the can had a microscopic number of charges moving a macroscopic distance.].

6. Charging Capacitor Plates with Opposite Charge (ball drums)

Assemble the arrangement shown in Figure 9 – try to NOT get oil from your fingers onto the ball thread, but get the ball to hang near the center of the gap between those capacitor plates. Touch one plate with a finger, and touch the other plate with the (running) VdG. Be patient if nothing happens right away – if the ball is neutral, it starts in an unstable equilibrium. Eventually it will "drum" between the plates.

When the ball touches the right plate, it is charged by { contact | induction } .

What sign of charge does it obtain there? { negative | positive } .

It accelerates left since it is { attracted | repelled } by { left | right } plate.

What happens to the ball's charge when it gets to the left plate?

Can this back-and-forth continue forever?

C. Conclusions & Clean-up

1. Which of the statements below were supported by your observations?
   - ☐ Like-sign charges attract each other.
   - ☐ Like-sign charges repel each other.
   - ☐ Opposite-sign charges attract each other.
   - ☐ Opposite-sign charges repel each other.
2. Which of the statements below are describe distance correctly?
   - ☐ distant charges repel a bit more strongly.
   - ☐ distance doesn't have much of an effect on the force.
   - ☐ nearby charges repel a bit more strongly.
   - ☐ nearby charges repel a lot more strongly
3. Re-write this statement, correcting its (multiple) errors:
   "Static electricity is charge that is often created by friction or heat."

4. A positively charged object probably had protons added to it. { True | False }

5. If charged object A touches (previously) neutral object B,
   then object A will { attract | repel } object B.
   Does it matter if object A or object B (or both) are insulators? Discuss

6. If charged object A induces a charge separation in (previously) neutral object B,
   then object A will { attract | repel } other B.
   Does it matter if object A or object B (or both) are insulators? Discuss

7. Explain how charging by contact is different from charging by induction: