How to Demonstrate the Voltage of a Charged Object in Physics Laboratory

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Abstract

Common Objects like a comb or a pen get charged when rubbed against something like human hair or garment clothing. Charged objects exhibit noticeable attractive or repulsive force lifting small pieces of paper or pushing/pulling a suspended light object charged with the same/opposite(uncharged) polarity respectively. This indicates the strong electrical nature of charged objects. Flashes due to spark between oppositely charged objects can be seen in total darkness. Implies a large potential difference between these charged objects which is not possible at lower voltages. This article describes a method to measure the voltage on commonly charged objects with respect to earth using simple instrumentation based on capacitors and CMOS voltmeter. Once the potential difference is known the average charge on the object can be calculated as well. The article also suggests a simple femto-farad capacitance meter for electrostatics work.

1 Introduction

The electrical nature of charged objects is ubiquitously encountered by the rubbing of a comb against human hair. The comb is negatively charged while the human body positively. Such a comb can attract small pieces of paper lifting them from the ground over a short distance. Or when brought again near body hair sparks with crackling sound could be heard. This electrical behaviour can also be seen with other objects as well like an ordinary plastic pen rubbed against suitable garment. Flashes of spark can be seen in total darkness when suitable garments or clothing are rubbed against eachother. All this implies strong electrical nature or possibly large amount of charge on these objects which is normally not seen with electrical equipment which operate at a few volts to a few hundred volts. To assess the electrical condition of these charged objects(like a plastic pen/narrow-cylinder or any other material brought to an appropriate form) a simple technique based on charging of capacitors is suggested which can be used for demonstration in a class room or to convince one self the potential difference to which these objects are brought with respect to earth(considered to be at zero potential and which easily lends a small quantity of charge with a negligible change in its potential) in this charge exchange process.

When two capacitors with a large difference in magnitude are charged in series it is seen that, while one(smaller) preserves the almost total potential difference across the combination the other(larger) preserves the almost total charge on the combination at a negligible potential difference across it. Now if the capacitances of both the capacitors are known then by measuring the voltage on one of them the voltage on the other can be determined. As such its the voltage on the larger capacitor with a greater quantity of charge and smaller voltage that would be preferred. A measurement of its voltage(i.e across $C_{\text{Large}}$) multiplied by the ratio of the capacitators($C_{\text{Large}}/C_{\text{Small}}$) would easily reveal the almost total potential difference across the combination. This very principle is applied here to determine the voltage on the charged object w.r.t earth.

2 The Apparatus

The apparatus is shown in figure 1, it consists of a cylinder(say a 330ml soda can) into which the object whose voltage w.r.t earth is to be determined is introduced. The object and the cylinder form a kind of capacitor system $C_1$ which is connected in series with another reference capacitor $C_2$ which is much larger(atleast 2 orders of magnitude) compared to $C_1$. For the dimensions considered in this article $C_1$ would be on the order of $\sim 1-5$ pico farad(pF). So our reference capacitor can be about a few to several 100 pF upto 1nF(or perhaps even more) depending on the intensity of charge on the object. The other end of $C_2$ is connected to
earth which supplies any small quantity of charge and maintains its zero potential. When the charged object is inserted into the cylinder the potential difference between it and the cylinder surface will cause charges to flow from earth through the reference capacitor (in the process charging it) to the cylinder. The cylinder capacitor would receive as much charge as required to maintain its surface nearly at the same potential as earth as it is unhindered by the large capacitor \( C_2 \). It should be mentioned here that as per our selection of its value the voltage drop developed across \( C_2 \) in the worst case is less than 10V and we guess the voltage on the charged object (\( \sim 10^3 \) V) is orders of magnitude higher than this, essentially 10V (or lower) is negligible compared to it. So we have the metal cylinder at nearly the same potential as earth (0V) and the total charge that flowed from earth to \( C_1 \) is stored in \( C_2 \). In view of the CMOS voltmeter suggested in this article the value of \( C_2 \) should be selected such that the voltage drop across it for a typical charge transfer is above 2.5V (if the -ve supply is 5V on the other hand if you choose 3V this would be 1.2V) and less than 10V.

To measure the potential difference on the charged object insert it into the cylinder with switch in the left position and then throw it to right to measure the voltage on \( C_2 \). The potential difference on the charged object w.r.t earth either positive or negative can be obtained as \( V_{C_2} \times C_2 / C_1 \). Care must be taken while connecting the capacitor \( C_2 \) to the voltmeter so that it has the right polarity. It is possible to determine quickly the polarity of an intensely charged object using a single transistor. For this wire the transistor using a suitable power source with a bright LED in the collector and protective resistor (10k\( \Omega \)) in the base circuit, now bring the charged object near the base resistor and observe the LED as the object is moved back and forth. Else one can use the electronic electroscope described in [5].
3 Summary

This article describes a simple experiment to demonstrate the voltage on a commonly charged object using simple low cost instrumentation. Author’s measurement of capacitance (C1) were between 2-3pF and voltages up to 2500-1500V respectively with use of C2=200pF-1nF and suggested instrumentation. For example in one case C1 ∼ 2.5pF, C2=1nF and V_{C2} ∼ -4.5V which yields a voltage of (C2/C1)V_{C2} ∼ -1800V for V_{C1}. It should be noted that the charged object loses its charge gradually and hence intense charge measurements should be carried out as quickly as possible.

4 Appendix

This appendix supplies the required two instruments in the experiment. However it’s possible to use any other standard instrument available/suitable. If you are using a standard configuration for C1 such that the capacitance of the system can be calculated then one does not need a capacitance meter. However its availability makes measurement of capacitance of any configuration possible eliminating constraint on configuration of C1.

4.1 High Impedance CMOS voltmeter

This voltmeter(Figure 2) is based on estimating the applied voltage(V_{in}) by bringing it in proximity to the threshold voltage(V_T) of a common CMOS gate by varying the supply voltage to the package itself. In [2] this is done manually however here to determine the voltage on the capacitor in a very short time a digital to analog converter is used, together with a flip-flop and an oscillator. Once the supply voltage to the CD4011 reaches an appropriate value such that V_{in} is just around V_T the clocking of the counter stops and so does the voltage variation across CD4011. From the voltage across it \(|V_{SS}|+V_{OP Amp}\) and by the knowledge of variation of V_T with supply voltage one can determine V_{in}, which would be actually equal to V_T corresponding to the supply voltage where the clocking stopped.
4.2 Femto Farad(fF) Capacitance Meter

Figure 3: Left: Suggested CMOS inverter gate based capacitance meter[3] which can measure capacitors on pico and femto scales. This is a very simple instrument which can be used in electrostatic experiments for the measurement of femto and pico farad capacitance when appropriately calibrated. The instrument exhibits good linearity with capacitance over 1000's of division. One can also use a DVM(2000mV) in place of a 100µA meter. It should be mentioned here that the above instrument with DVM indicated nearly the same value as printed on the commercial capacitor from 500fF to 22pF. Right: Capacitance of distributed conductors, here conductors 1 & 3 and 2 & 4 are at same potential V and V' respectively. When different conductors are connected together cross capacitance between different parts has to be taken into account during estimation of desired capacitance(here C\textsubscript{34}).

The capacitance meter[3] suggested in Figure 3 can measure very low capacitances down to $10^{-14}$F. The capacitance due to connected leads can also be nulled by using set-zero potentiometer. The range/calibration (F/div) of the instrument can be set with the help of the set-FSD resistor(moving coil meter) and also by varying the supply voltage(in this view the supply voltage has to be stable and strictly regulated). The instrument is based on charging a capacitor with a constant low current between two different voltages to produce a delay in a closed loop duty cycle compensated 180° out of phase gate astable drive. It can measure capacitances on the order of $10^{-14}$F(10 fF) to $10^{-9}$F(nF). It should be cautioned that measurement of distributed capacitance is not as straight forward as compact localized capacitance like that of a commercial capacitor or a twisted pair of wires. During measurement of distributed capacitance care must be taken to account for the cross capacitance terms between different parts of the conductors[4].

References

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