PAPER

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Low cost device to study static electricity and to verify the polarity of the charge on the surface of the materials in the triboelectric series

Rohan D Lahane and Arvind Paranjpye

Nehru Planetarium, Nehru Centre, Dr. Annie Besant Road, Worli, Mumbai 400 018, India

E-mail: rohan.lahane@gmail.com

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Abstract
Students are introduced to the concepts of static electricity at a school level and an under-graduate level. In this paper, we present an inexpensive and portable device that can be used to study the static electricity and verify polarity of the electric charge on materials in a triboelectric series. This device is developed at the Science Laboratory, Nehru Planetarium (Mumbai), India. It has wide applications as an educational tool to teach the fundamental concepts of electrostatics in a simpler way.

Keywords: electroscope, static electricity, triboelectric series

1. Introduction

Static electricity is said to be the electric charges developed on bodies when rubbed against each other. In our childhood, we have observed that when a plastic ruler is rubbed with human hair and taken near to pieces of paper, the paper pieces are attracted towards the plastic ruler. We all experience static electricity in our daily life too. For instance, the crackling sound when we take off our sweater in Winter; and when we place our hands closer to older generation cathode ray tube television screens, the hairs on our hands are raised up straight. The reason for these experiences is discharge of electric charges through our body, which are developed and accumulated due to rubbing of insulating surfaces.

A classroom demonstration shows the deflection of a suspended plastic straw when a plastic pipe rubbed with wool or a glass rod rubbed with silk cloth is brought into its vicinity. This is a typical demonstration to study static electricity. Another laboratory device, a gold leaf electroscope, is used to show the presence of charges on the surface of the plastic pipe and glass rod. The repulsion of gold leaves in the electroscope concludes that the surface has the same kind of charge present. By convention, the charge on the glass

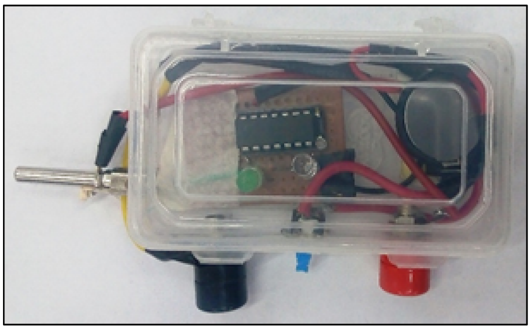

Figure 1. Electronic electroscope.

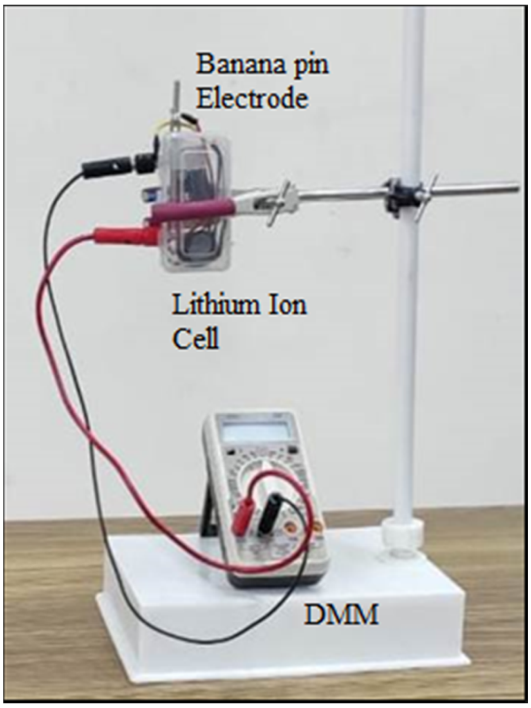

Figure 2. The entire assembly.

rod rubbed on wool is said to be positive and the charge on the plastic pipe rubbed on the silk cloth is negative. The process in which certain materials become electrically charged after they are separated from a different material in which they were in contact is known as *triboelectric charging*. This happens due to transfer of electrons between the two materials in contact. Various materials have the tendency of either giving up electrons and becoming positive in charge or attracting electrons and becoming negative in charge when rubbed against each other. The list of such materials is called the *triboelectric series*. In some recent studies, the polarity of the charge of the triboelectric materials was detected using p-channel and n-channel MOSFETs [1], an indicator connected with bipolar transistors [2, 3], or using an AND gate interfaced with an LED [4].

In this paper, we present an inexpensive and compact device which can be used to verify the polarity of the electric charge on the surface of a given material. The device consists of a low-cost high-speed CMOS Quad 2-Input NAND gate IC interfaced with a banana pin and two different

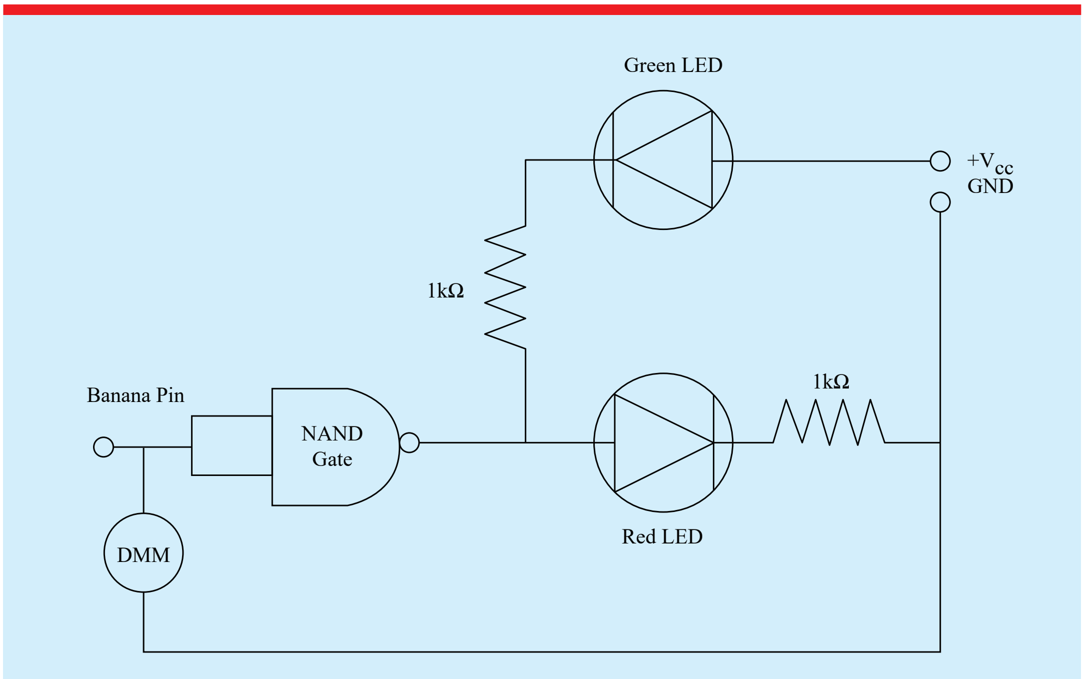

Figure 3. Circuit diagram.

coloured LEDs (red and green) as polarity indicators, as shown in figure 1. Also, a push-button is provided to manually switch the device ON and OFF. The banana pin serves as a receiver and gives an indication of the presence of electric charge through an LED. The entire circuit with the LEDs is enclosed in a plastic case. A digital multi-meter is connected between the banana pin and ground to show the polarity of the electric charge present on the tip of a banana pin. The entire assembly is shown in figure 2. The plastic casing may accumulate the charges on its surface to avoid the accumulation of the charges; the circuit is mounted on wooden strip before encasing. The device can be dried using an air blower before use.

2. Device and method

2.1. Quad 2-input NAND gate

The IC M74HC00 is a 14-pin Quad 2-Input NAND gate [5]. It has four independent 2 input NAND gates to perform the logical NAND operation. This IC is low cost and a good alternative for MC14081 [4]. It requires a supply voltage between 2 V and 7 V. Therefore, we have used a lithium ion coin cell (CR2032), which provides a constant supply of 3 V.

2.2. Banana pin, LED's and diode

A simple banana jack pin (4 mm) is used as a sensor which gathers the charge over its tip. A wire is soldered to its metal connector by removing the outer plastic cover. Two LEDs i.e. one red color and one green color led (5 mm, 0.5 watt), are used as indicators in the circuit.

2.3. Interfacing NAND gate to banana jack pin and the LEDs

Figure 3 shows the complete circuit diagram. Figure 4 shows the printed circuit board layout made using the software ExpressPcb©. The metallic part of the banana jack pin is connected between pins 1 and 2 of the NAND gate IC, which are inputs of the NAND gate. A red color LED is connected between pin 3 of the NAND gate (output) and pin 7 (GND). A green LED is connected between pin 3 and pin 14 ($+V_{cc}$) in a reversed biased position. A current limiting resistor of 1 kΩ

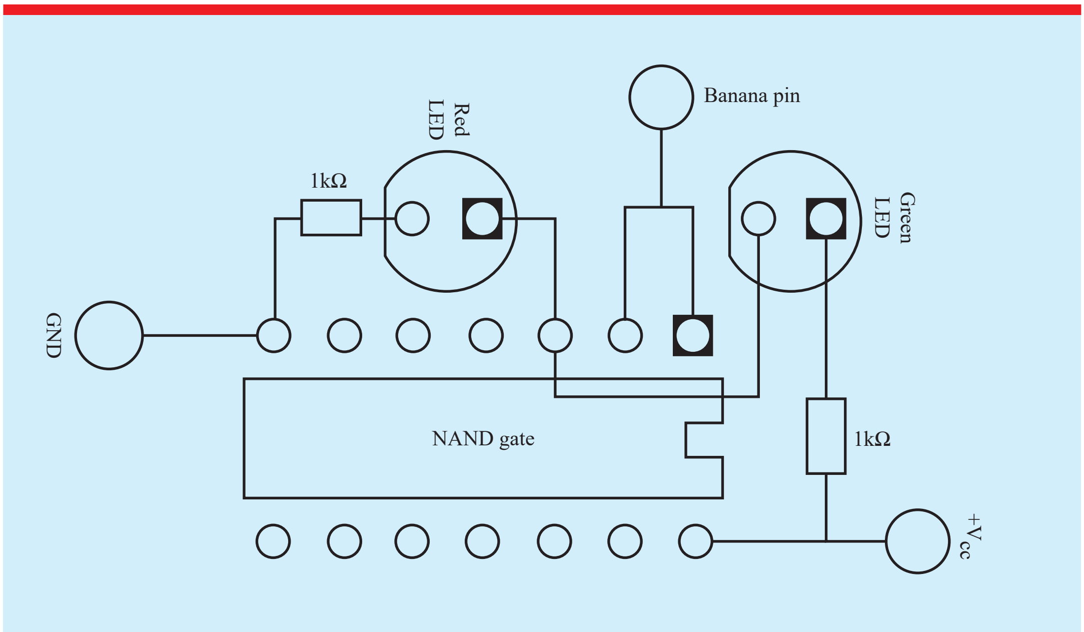

Figure 4. PCB layout.

is connected externally to each of the LEDs, as shown in the circuit diagram (the value of the resistor is not critical; it can be changed to lower values to increase the brightness of the LED). A lithium ion button cell of 3 V is used to power the NAND gate IC.

2.4. Need for a read-out device

In the earlier studies [1, 2], to show the presence of an electric charge on the material, which is brought near the banana pin, a single LED was used as the indicator. But which kind of electric charge (polarity) is present on the given material was not attempted. A simple digital multimeter is used as a read-out device to serve the purpose. The digital multimeter is interfaced to the electroscope, using wires connected to the sockets provided on the device, as shown in figure 5.

3. Working of the device

3.1. Colour LEDs as an indicator

In earlier attempts, to show the presence of an electric charge on the material, which is brought near the banana pin, a single LED was used as the indicator. Here, we have used two LEDs of different colors to indicate two types of charges. This device uses only one gate. When the circuit is powered by a lithium ion cell, either of the LEDs glow, indicating that the electroscope is functional. When two different materials are rubbed against each other, one of the materials will lose electrons and acquire positive charge and the other gains electrons and becomes negatively charged. When the negatively charged material is brought closer to the tip of banana jack pin, the red LED glows indicating the presence of negative charge on that material. Similarly, when the other material is brought closer to the tip of banana jack pin, the green LED glows indicating positive charge on the material.

The materials we used to demonstrate the above experiment were a PVC pipe rubbed on wool and a glass rod rubbed on silk cloth. When a PVC pipe was rubbed against the wool and brought closer to the tip of the banana jack pin, the red color LED glowed, indicating the presence of negative charge. Similarly, when the glass rod rubbed against the silk cloth is brought near the tip of the banana jack pin, the green color LED glowed, indicating the presence of positive charge. The indication of presence of negative and

Figure 5. Digital multimeter connected to the electronic electroscope.

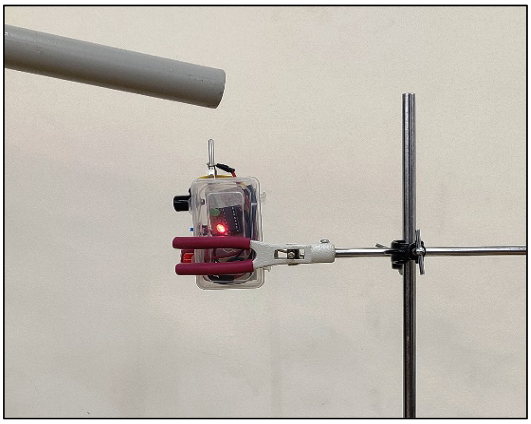

Figure 6. The red color LED indicating the presence of negative charge for the PVC pipe.

positive charge by respective LEDs is shown in figures 6 and 7.

3.2. Read-out device for verification of sign of the electric charge

For verifying whether charge present on the material is positive or negative, a read-out device is essential. Here, the read-out device used is a simple digital multimeter operating in the millivolts (mV) range.

To serve the above purpose, we rubbed a PVC pipe with wool and a glass rod with silk cloth. When a PVC pipe was rubbed on wool and brought near the tip of the banana jack pin, the digital multimeter showed a negative sign along with some voltage values in the millivolt range. Similarly, when the glass rod was rubbed on silk cloth and brought near the tip of the banana jack

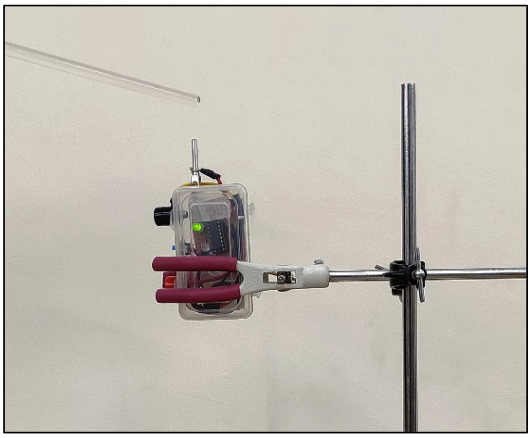

Figure 7. The green color LED indicating the presence of positive charge for the glass rod.

Table 1. Polarity of the charge verified using our electroscope for various triboelectric series materials.

Materials	Polarity of the charge
Human hands, skin	Positive
Glass	Positive
Wool	Positive
Paper	Positive
Cotton	Neutral
Steel	Neutral
Wood	Negative
Rubber balloon	Negative
Styrofoam	Negative
Poly vinyl chloride (PVC)	Negative
Teflon	Negative

pin, the digital multimeter showed a positive sign with some voltage values in the millivolt range

The digital multimeter showing the polarity of the charge present on a PVC pipe and on the glass rods along with some values in the millivolt range are shown in figures 8 and 9, respectively.

4. Results and discussion

Using the device, we verified the polarity of the charge present on the surface of the different materials. Some of the best combinations of materials from triboelectric series (one from the positive charge list and the other from the negative charge list) were chosen and the polarity of the charge on the surface of these materials was verified. These measurements were taken by placing the material in the range of 2–5 cm from the tip of the sensor (banana jack pin). The precise quantitative analysis of the charge value present on the material requires more definite methods, since it is primarily dependent on the distance of the material from the sensor and many other factors.

This device is useful for determining which materials have the greatest tendency to attract electrons and become more negative in charge, and vice versa. We can also verify which materials are electrically neutral and have zero tendencies to gain or lose electrons. This is indicated in table 1.

5. Conclusion

The device can be very useful to demonstrate the basic concepts of electrostatics at a school level. It is sensitive enough to read charges on the material at a few centimeters. Hence, it can be used to measure the field range of the electric charges as a function of the distance between the material and the sensor. The advantage of this assembly that it is made using low cost components and can be easily replicated in various schools, colleges and other educational institutes.

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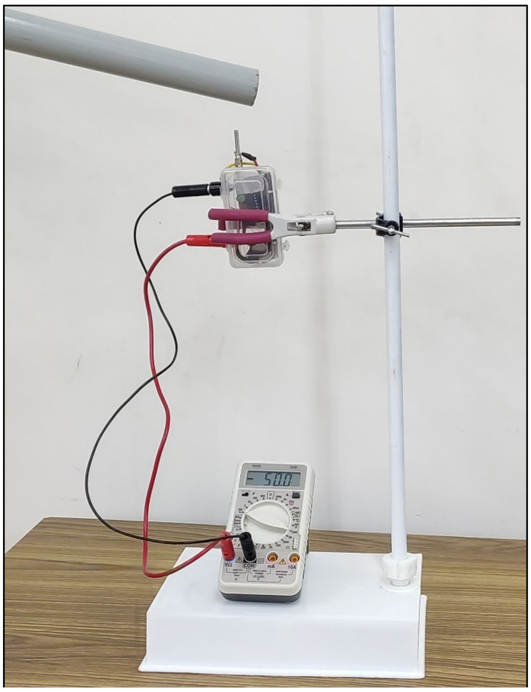

Figure 8. Digital multimeter showing negative polarity for a PVC pipe.

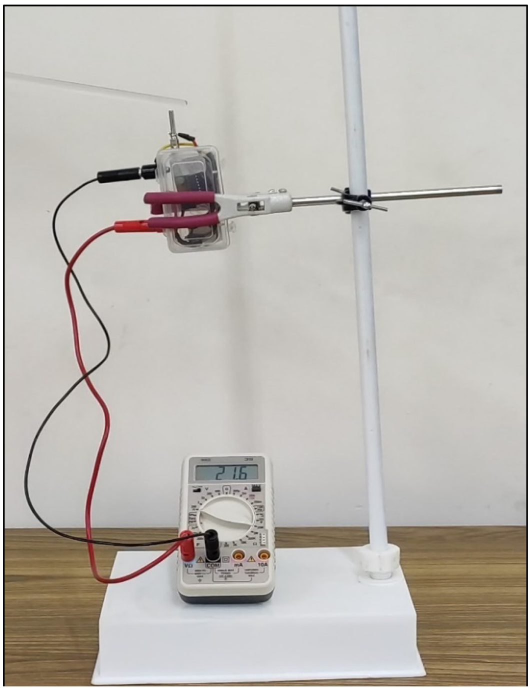

Figure 9. Digital multimeter showing positive sign for a glass rod.

development stages of the power supply. Also, we like to put on record the help and support readily provided by the Nehru Centre, Mumbai.

ORCID iD

Rohan D Lahane https://orcid.org/0000-0002-3305-7770

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Rohan D Lahane is a Science Educator (MSc) at the Science Laboratory, Nehru Planetarium, India. His research interest focuses on developing low cost instruments and experimental setups for teaching concepts of science through hands-on activities for students, at mid-school level.

Arvind Paranjpye is a Director of the Nehru Planetarium, India. He is actively involved in teaching and conducting workshops in astronomy and developing astro-models and activity kits for students and teachers, at mid-school level.