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A Simple Portable Handheld Van de Graaff Generator for Demonstrating Static Electricity

Dinar Maftukh Fajar[1,*], Muhammad Sholehuddin[2], and Muhammad Habibbulloh[3]
[1]Natural Science Education Study Program,
Universitas Islam Negeri Kiai Haji Achmad Siddiq Jember, Jember, Indonesia
[2]Master Program of Science Education, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia
[3] Department of Physics, Universitas Negeri Surabaya, Surabaya, Indonesia
dinarmaftukh@uinkhas.ac.id

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Abstract

One device that is commonly used to demonstrate electrostatic phenomena is the Van de Graaff generator. However, this device is found to be expensive, relatively large, hard to move, and not available in many school laboratories. This paper aims to describe the experiment of creating a simple portable handheld Van de Graaff generator produced by employing second and easily available materials in the local market. This device collects charges from two materials that rub against each other. The combination of chosen materials listed in the triboelectric series determines the type of charge on the generator. This research used the experimental method by continuously testing the prototype to find the best result using the following steps: start, theory, design, material selection and assembly, testing, completion, and finish. A charge conduction experiment and a charge type test through a simple Coulomb experiment or an electrostatic polarity detector successfully tested the final product. The results showed that the device could effectively demonstrate basic electrostatic phenomena, making it a practical and affordable alternative for classroom demonstration.

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INTRODUCTION

Electrostatics is one physics topic commonly studied at diverse levels in schools and universities. This topic discusses electric charges, electric fields, electric potentials, and various interactions that involve them. The electric charges are very small objects, so in their teaching, models are always used for visualization (Casperson & Linn, 2006). The discussion about electric charges tends to be abstract and intuitive and has many mathematical formulas (Chang, 2011; MacGorman et al., 1998). Electrostatics is often considered difficult to study, and there are various misconceptions (Chang, 2011; Garrido et al., 2019; Hermawati et al., 2017; Hermita et al., 2017; Priyanto et al., 2018; Purwanto et al., 2019). Furthermore, the teaching methods that are not in accordance with the characteristics of this topic make learning unpleasant (Mazibe et al., 2020). Even ordinary learning resources (books, audio-visual props, etc.) are not enough to help students understand the concept of electrostatics (Maison et al., 2021).

Demonstration is commonly used to present something abstract in concrete (Berthold & Renkl, 2009; Min et al., 2017). Various studies have documented the effectiveness of demonstration methods on the success of learning physics (Garrido et al., 2019; Ning, 2008; Soe & Nyun, 2018). By demonstration, various senses (audio, visual, and kinesthetic) are involved in learning activities to accelerate conceptual understanding and strengthen long-term memory. In addition, it only requires a few tools to present a demonstration that many individuals can see in the class.

The phenomena that can be demonstrated in static electricity are relatively limited (Ahlers, 2009). A phenomenon known to most people is electrostatic discharge, when a charged person puts their fingers close to a metallic car or door (Kikunaga & NaoTerasaki, 2022). Some simple models that are presented mainly by teachers are a comb that can attract cuts of paper after being rubbed with dry hair, a charged plastic object that can make electroscope leaves open after being brought up, or how lightning (from cloud to cloud, from cloud to earth, and vice versa) works that are usually demonstrated through slides or video (Sudhira et al., 2022). Due to this limitation, a static electricity teaching aid must be developed to present the various electrostatic phenomena.

Apart from the electroscope, several props used to demonstrate electrostatic phenomena are the Wimshurst machine and the Van de Graaff Generator. This latter device is better known than the first one. The Van de Graaf Generator (VDGG) is a prop designed to generate static electricity from friction between two dissimilar materials (Alharbi et al., 2019; Beaver & Powers, 2010). VDGG can display charge transfer, electric field lines (both phenomena are commonly demonstrated by the standing hair of the person touching it), charge separation, and even artificial lightning. However, because of its expensive price, most school laboratories do not own VDGG. It was also found that the VDGG ordinarily produced in the market is relatively large and heavy, so it can only be used statically.

A similar previous study on the VDGG was conducted by Wildan et al. (2022), who had successfully developed an augmented reality-based van de Graaff. However, the experiment of simple portable VDGG created from second-hand stuff and easily available materials in the local market needs to be clearly explored.

Based on this case, the same tool can be developed with available and affordable materials, mini-sized so that it is easy to lift, and can be demonstrated dynamically in the class using the working principle of the VDGG. Therefore, this paper will describe the experiment of a simple portable handheld VDGG as well as several tests regarding electrostatics demonstration.

METHODS

This research utilizes experimental methods to find the most suitable design, selected materials, and the best performance of the simple portable handheld VDGG. The experiment steps modified from Berger et al. (2017) are described in Figure 1.

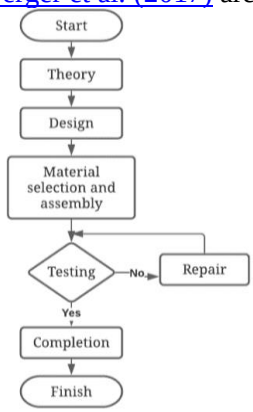


Figure 1 Flowchart of experiment

The results are continuously tested until they are close to the original VDGG. The tests carried out include charging by conduction and induction, testing the type of charge with the Coulomb experiment, and testing the type of charge with an electrostatic polarity detector.

RESULTS AND DISCUSSION

Portable Handheld Van de Graaff Generator (VDGG) Design

Charging by friction is one of the static electricity concepts studied in the middle school physics curriculum. There are three methods of charging: friction, induction, and conduction. In the friction process, two neutral objects rubbed together will generate charges; one object becomes positively charged, while the other becomes negatively charged, depending on their electron affinity. Experts in the triboelectric series have arranged the sequence of these materials. The middle school physics curriculum introduces types of charging, atomic components, properties of electric charges, and charge interactions with simple calculations. At the high school level, more complex vector calculations are taught. The VDGG can be used to demonstrate these concepts (Sadly & Akhsan, 2023).

How the portable handheld VDGG works is described in Figure 2. This figure is a portable handheld VDGG design developed in this study. The parts include: (1) head made of metal or used cans; (2) belt; (3) power supply/battery; (4) DC motor; (5) switch; (6) fiber cable to the head and the ground; (7) bearing; (8) top roller; (9) lower roller; (10) PVC pipe; and (11) base.

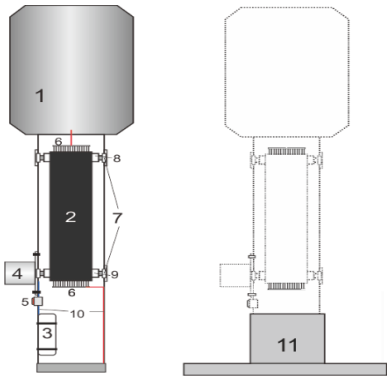


Figure 2 Portable handheld VDGG design

In principle, VDGG produces electric charges using the friction method. This friction occurs between the belt (2) and the lower roller (9), which is repeatedly driven by the motor (4), causing a negative electric charge to the belt (2). The friction between the rubber belt (2) and the upper roller (8) creates a positive electric charge on the rubber belt. Simon's research explained that the belt of VDGG was charged by the frictional electricity created between the belt and the roller (Simon, 1975). This charge is transferred via the upper fiber cable (6) and flows into the dome. The rest of the belt will be neutralized via the ground wire (6).

Product

The portable handheld VDGG developed in Figure 3 has undergone several tests for maximum performance. The simple portable handheld VDGG is assembled of the following materials: an aluminum drink can for the VDGG head, a 1.25-inch PVC pipe with a length of 28 cm for the VDGG body, a used compact disk for the VDGG base, a 12 V DC motor, 12-volt adapters, and fiber cables. For positive VDGG, use nylon for the top

roller and silicone for the lower roller, and vice versa for negative VDGG, use silicone for the top roller and nylon for the lower roller. Both use PVC for the belts.

(a) (b) (c)

Figure 3 The final product: (a) complete view, (b) upper roller, (c) base

The difference between positive and negative VDGG is the materials used in the rollers and belts, which are sequential in the Triboelectric series (Khalid et al., 2018): nylon, PVC, and silicone. In positive VDGG, the top roller made of nylon, which rubs against the PVC belt, will make the nylon positively charged, and the charge will be transmitted to the VDGG head. Conversely, for negative VDGG, the top roller made of silicon, which rubs against the PVC belt, will make the silicon positively charged, and the charge will be transmitted to the VDGG head. To make it easier to identify, a positive VDGG head is assembled from a green drink can, while a negative VDGG head is constructed from an orange drink can.

Some trial experiments have been carried out by testing various materials: the belt using silicone tape and plastic rollers and the belt using silicone tape and rubber rollers. However, the results obtained are not as optimal as using the materials presented. This stainless portable VDGG mass weighs 195 grams, making it relatively light to hold. Measures have also been carried out by replacing the 4-battery power supply with a 3.7 V charger, but the products obtained are heavier and more challenging to lift.

Charging Test

Figure 4 shows how portable handheld VDGG can demonstrate an experiment of charging by conduction. In Figure 4 (a), eight sheets of tissue paper glued around the positive portable VDGG head are initially neutral in a dropping position. After the portable VDGG is switched on, the tissue paper pieces become positively charged because they are in contact (conducted) with positive VDGG. Since they both have the same charge, each piece spread out and was lifted to a height of 4 cm above the head of VDGG. This experiment was also successful in negative VDGG.

(a) (b)

Figure 4 Demonstration of charging by conduction: (a) raising paper cuts and (b) flying aluminum foil

Experiments have also been carried out by replacing the tissue with aluminum foil, but the raised pieces are not as high as the pieces of tissue paper. The result should be better because the aluminum foil is a conductor. This is presumably due to the influence of the mass of aluminum foil, which is relatively large and the same size as tissue paper. Another finding is that the success of this experiment also confirms that the lower the humidity (in a room without air conditioning), the stronger the electrostatic effect, as reported by Wan (Wan et al., 2013).

A similar phenomenon occurs in Figure 4(b). Firstly, several neutral sheets of aluminum foil are stacked on top of the negative VDGG head. After the VDGG was switched on, each aluminum foil was negatively charged because it was in contact with negative VDGG. The same type of charge makes each sheet of aluminum foil repel each other and fly into the air. However, this demonstration will be more successful if another object (such as a finger) is held close to the aluminum foil to help pull it up. This also proves that the charges of the object are induced (charging by induction), where the part of the object that is close to the aluminum foil is positively charged while the other part is negatively charged. Here, the teacher's explanation is needed to avoid misconceptions. The charged objects can attract neutral objects with this kind of mechanism.

Polarity Test

It was previously mentioned that portable VDGGs were developed with two different charges. The cause of the difference is the materials used in the rollers and belts. A polarity test is conducted to test whether the VDGG has a positive or negative charge. This test is pivotal because a certain type of charge on an object is known; other objects' charges can also be identified as the charge from the electrostatic interactions. Knowing the type of charge on this VDGG is the first step in demonstrating the triboelectric series experiment and induced charge charging. Another method of constructing a VDGG is to use the triboelectric effect (Bond & Hughes, 2013b, 2013a).

Polarity Test by Coulomb Experiment

In simple terms, the Coulomb experiment shows the interaction of two charged objects, where objects with the same charges will repel, and those with opposite charges will attract (Rianna et al., 2021). The condition that should be met is that the charge of one object must be known. The triboelectric series can determine the type of charge of the rubbing object. The demonstrating Coulomb experiment is shown in Figure 5.

Figure 5 (a) shows an upright T-shaped rod with a sturdy stand to be used as a demonstration aid for Coulomb's law. A PVC rod and a glass rod (Plexiglas) are hung at the ends of its arms. Wool and silk fabrics for charging the rods by rubbing are also provided underneath. According to the triboelectric series, PVC rods are negatively charged when wool is rubbed. In Figure 5 (b), if positive VDGG is brought near the PVC rod, the PVC rod will be attracted and move to follow the VDGG position because they have opposite charges.

The demonstration can also be varied by replacing positive VDGG with negative VDGG, silk cloth-rubbed PVC rods (PVC becomes negative), Plexiglas rods rubbed with wool (Plexiglas becomes positive), and silk cloth-rubbed PVC bars (PVC becomes negative). The triboelectric effect and the Coulomb law can be clearly demonstrated through systematic experimental steps.

(a) (b)

Figure 5 Demonstrating Coulomb Experiment: (a) PVC rod, plexiglass rod, wool fabrics, and silk fabrics; (b) positive VDGG attracts PVC pipe rubbed by wool.

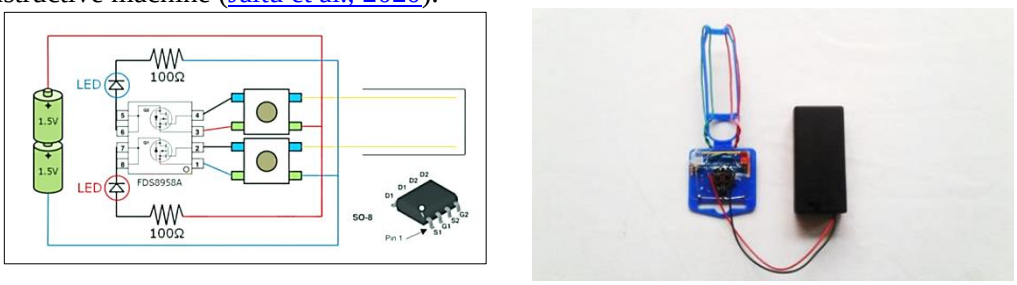
Polarity Test by Electrostatic Polarity Detector (EPD)

The test was also carried out using an EPD to confirm the results of Coulomb's Law experiment. EPD is a device that can determine the type of charge of objects brought close to it. Various researchers have developed several EPD designs (Lahane & Paranjpye, 2020; Yavaş & Karadag, 2019). Most of these tools are MOSFET-based, which manipulates the amount of electric current due to variations in the electric field it receives. In this tool, the red and blue LEDs will light up when an object with a positive and negative charge approaches.

The EPD used in this study is adopted from Yavas and Karadag's design using MOSFET NDP6020P as P-channel and IRLB8721 as n-channel (Lahane & Paranjpye, 2020). However, Figure 6(a) shows that the design is modified using the dual MOSFET FDS8958a. This is because the FDS5859a Mosfet is more compatible with low power. Secondly, regarding efficiency, the FDS5859a Mosfet is a dual MOSFET that supports both p and n channels for low voltage, like other MOSFETs. Another reason is that this MOSFET is more readily available in the local market. Figure 6 (b) describes the EPD made in the test.

Figures 6 (c) and (d) describe that the two VDGGs have shown the same type of charge with the EPD indicator; that is, the red LED lights up when brought closer to positive VDGG, and the blue LED lights up when brought closer to negative VDGG.

The advantages of this portable handheld VDGG are (1) it consists of two types of charge (positive portable VDGG and negative portable VDGG), (2) it is made of used materials, it is simple, inexpensive, and easy to obtain, and (3) it is portable and smaller than on regular VDGG. Other studies have shown that VDGG, apart from being used to demonstrate static electricity, can be a safe, inexpensive, and fast method to recover the electrical charge of polypropylene lost during sterilization (Sugihara, 2021). The research by Jaitu et al. explains that the Van de Graff Generator, in its simplest form, is a very instructive machine (Jaitu et al., 2020).



(a) (b)

(c)

(d)

Figure 6 Polarity test by EPD: (a) circuit; (b) product; (c) red LED lights up when EPD brought closer to positive VDGG; (d) blue LED lights up when EPD brought closer to negative VDGG

CONCLUSION

The experiment of a simple portable handheld Van de Graaff generator has been reported. It utilizes simple or recycled items to demonstrate electrostatic phenomena. This teaching aid considers availability, cost, and environmental factors. Developing low-cost teaching aids is useful for building efficiency and creativity and supporting an environmental care attitude for students and the creators.

Although this product has gone through several trials and errors to find the most appropriate material for the motor, belt, and roller components, it can still strive for better performance by modifying the three parts. In this study, researchers have been unable to measure the rotational speed of the motor used. It will be predicted better if the product uses a motor with a larger speed of the same size.

Future research that can be recommended is how to design classroom learning by utilizing this tool. This product is useful for teaching science subjects about static electricity, including the nature of electric charge, charge transfer, charge separation, and Coulomb's law, at the junior high school level. Besides the above-mentioned, this tool can demonstrate geometric vectors and calculations of more complex electrostatic phenomena at the high school level.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

DMF contributed to the conceptualization, methodology, investigation, product trials, instrument design, and final draft preparation. MS participated in product trials, data analysis, and report writing, while MH provided validation and consultation on writing and references.

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AUTHOR PROFILES

Dinar Maftukh Fajar
Assistant professor, Science Education Study Program, Universitas Islam Negeri Kiai Haji Achmad Siddiq Jember, Indonesia. Research interests are physics and astronomy education.
ID Google Scholar: lUCJzzkAAAAJ
ID Sinta: 6683597
ID Orcid: 0000-0002-7473-4053

Muhammad Sholehuddin
Postgraduate Student, Master of Science Education, Yogyakarta State University. Research interests are physics and natural science education.
ID Sinta: 6931226
ID Orcid: 0000-0002-1314-1502

Muhammad Habibbulloh
Assistant professor in Physics Department, Universitas Negeri Surabaya, Indonesia. Incorporated in the expertise cluster of learning media lecturers with research interests are physics education and science education
ID Google Scholar: j42fH1UAAAAJ
ID Sinta: 6800912
ID Orcid: 0000-0003-0667-5044
ID Scopus: 57201664867