ST. JOHN BAPTIST DE LA SALLE CATHOLIC SCHOOL

Physics Assignment

Topic: Applications of Electrostatics

Submitted to: Aaron GK

Grade 10A

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Acknowledgment

We want to start by giving thanks to God for his assistance. In addition, we appreciate our teacher giving us this assignment because it helped us in having better understanding about applications of electrostatics.
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Table of Contents

1. Introduction

Electrostatics is the study of electromagnetic phenomena that occur when there are no moving charges—i.e., after a static equilibrium has been established. Charges reach their equilibrium positions rapidly, because the electric force is extremely strong. The mathematical methods of electrostatics make it possible to calculate the distributions of the electric field and of the electric potential from a known configuration of charges, conductors, and insulators. Conversely, given a set of conductors with known potentials, it is possible to calculate electric fields in regions between the conductors and to determine the charge distribution on the surface of the conductors. The electric energy of a set of charges at rest can be viewed from the standpoint of the work required to assemble the charges; alternatively, the energy also can be considered to reside in the electric field produced by this assembly of charges. Finally, energy can be stored in a capacitor; the energy required to charge such a device is stored in it as electrostatic energy of the electric field.

2. Applications of electrostatics

There are so many things that use electrostatics; however, from this let's see some of its application here below.

2.1. Van De Graaff Generator

A Van de Graaff generator is an electrostatic generator, created by an American physicist Robert, which generates extremely high electric potentials by accumulating electric charge on a hollow metal globe on top of an insulated column using a moving belt. At low current levels, it generates direct current (DC) electricity at very high voltages.

Modern Van de Graaff generators have a potential difference of up to 5 megavolts. The model can generate roughly 100 kV and store enough power to cause audible electric sparks. Larger Van de Graaff machines are on site in some scientific museums; smaller ones are created for enjoyment and physics education to explain electrostatics.

As a result of the Van de Graaff generator's remarkable potential for accelerating subatomic particles to extremely high speeds in an evacuated tube was initially created as a particle accelerator for physics study. Before the invention of the cyclotron in the 1930s, it was the most potent type of accelerator. Van de Graaff generators are commonly used as accelerators to produce intense particle and X-ray radiation for nuclear medicine and research.

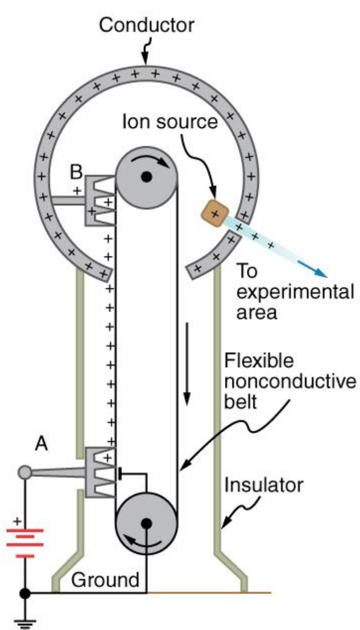
Arcing and corona discharge restrict the voltage generated by an open-air Van de Graaff machine to roughly 5 MV. Most contemporary industrial machinery is housed in pressurized tanks filled with an insulating gas that allows for potentials up to roughly 25 MV.

2.1.1. The way Van De Graaff Generator Work

Static electricity serves as the only operating principle for the Van De Graaff generator. As we all know, all matter is composed of atoms, which are further divided into protons, neutrons, and electrons.

Protons are thought to be positively charged, whereas electrons are thought to have a negative charge. The matter is regarded as neutrally charged when both the quantity of protons and electrons stays constant. The proportion of electrons to protons is greater in negatively charged materials than in positively charged matter. Electrons can move between different types of substances or matter.

Based on the triboelectric characteristics of two materials, an electron flow may occur when they are rubbed together. The substance that sheds electrons will become positively charged due to the transfer, whereas the material that got electrons will become negatively charged. That’s how static electricity is produced. Static electricity is generated using a Van de Graaff generator. A Van de Graaff generator’s constant current is accompanied by variable voltage depending on the supplied load. The components of a very basic Van de Graaff generator are as follows:



- A motor
- Insulated belt
- Two Rollers
- The metal sphere as the output terminal
- Two Brush assemblies

The motor must rotate the belt around two rollers at a steady speed. The material used to construct the lower roller has a greater triboelectric characteristic. Electrons are collected from the insulated belt onto the bottom roller as the motor begins rotating the belt around it. The charge gradually concentrates more and more on the roller.

This charge concentration event repels the electrons at the brush assembly's tips. The air molecules here between the bottom roller and brush assembly begin to attract electrons as well.

This phenomenon results in the positively charged air molecules transported on the belt from the negatively charged roller. As a result, the belt receives a positive charge and travels in the direction of the upper rollers.

Due to its construction or covering of material from a higher position in the triboelectric series, such as nylon, the top roller tries to resist the positive charge on the belt. The top brush reaches the upper roller and belt at one end and is directly attached to the interior of the output node or sphere.

The positive charges on the belt draw the electrons into the brush. Air particles dissolve there too, and the liberated electrons travel in the direction of the belt. The sphere absorbs the entire charge, and any extra charge is dispersed outside the sphere or terminal output.
This straightforward electrostatic action enables the Van De Graaff generator to produce high voltages continuously.

2.2. Xerography

Most copy machines use an electrostatic process called xerography—a word coined from the Greek words xeros for dry and graphos for writing. The heart of the process is shown in simplified form in Figure below.

A selenium-coated aluminum drum is sprayed with positive charge from points on a device called a corotron. Selenium is a substance with an interesting property—it is a photoconductor. That is, selenium is an insulator when in the dark and a conductor when exposed to light.

In the first stage of the xerography process, the conducting aluminum drum is grounded so that a negative charge is induced under the thin layer of uniformly positively charged selenium. In the second stage, the surface of the drum is exposed to the image of whatever is to be copied. Where the image is light, the selenium becomes conducting, and the positive charge is neutralized. In dark areas, the positive charge remains, and so the image has been transferred to the drum.

The third stage takes a dry black powder, called toner, and sprays it with a negative charge so that it will be attracted to the positive regions of the drum. Next, a blank piece of paper is given a greater positive charge than on the drum so that it will pull the toner from the drum. Finally, the paper and electrostatically held toner are passed through heated pressure rollers, which melt and permanently adhere the toner within the fibers of the paper.

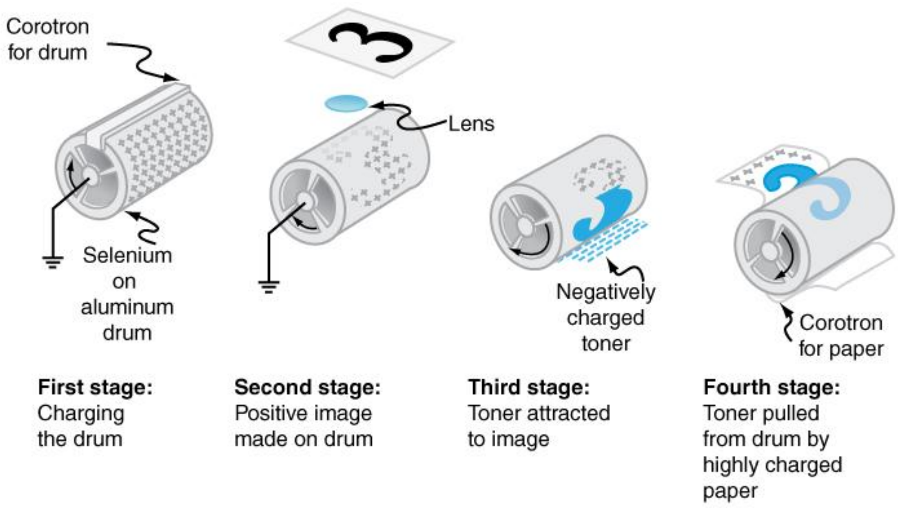


Figure: Xerography is a dry copying process based on electrostatics. The major steps in the process are the charging of the photoconducting drum, transfer of an image creating a positive charge duplicate, attraction of toner to the charged parts of the drum, and transfer of toner to the paper. Not shown are heat treatment of the paper and cleansing of the drum for the next copy.

2.3. Ink Jet Printers

The ink jet printer commonly used to print computer-generated text and graphics, also employs electrostatics. A nozzle makes a fine spray of tiny ink droplets, which are then given an electrostatic charge. (See the figure down below) Once charged, the droplets can be directed, using pairs of charged plates, with great precision to form letters and images on paper. Ink jet printers can produce color images by using a black jet and three other jets with primary colors, usually cyan, magenta, and yellow, much as a color television produces color. (This is more difficult with xerography, requiring multiple drums and toners.)

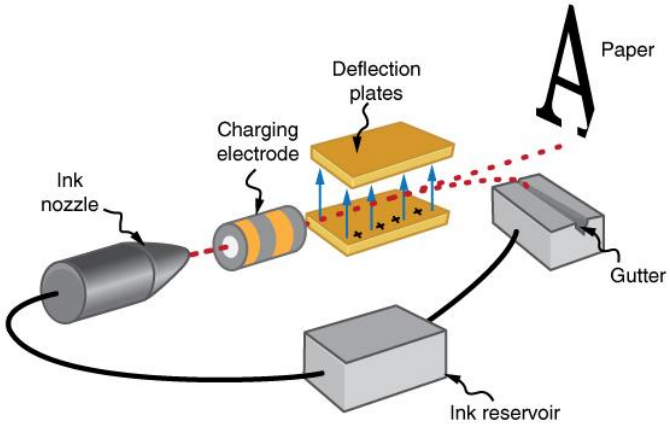


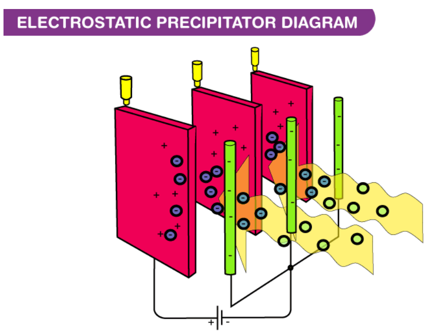
Figure of: The nozzle of an ink-jet printer produces small ink droplets, which are sprayed with electrostatic charge. Various computer-driven devices are then used to direct the droplets to the correct positions on a page.

Electrostatic painting employs electrostatic charge to spray paint onto odd-shaped surfaces. Mutual repulsion of like charges causes the paint to fly away from its source. Surface tension forms drops, which are then attracted by unlike charges to the surface to be painted. Electrostatic painting can reach those hard-to-get at places, applying an even coat in a controlled manner. If the object is a conductor, the electric field is perpendicular to the surface, tending to bring the drops in perpendicularly. Corners and points on conductors will receive extra paint. Felt can similarly be applied.

2.4. Electrostatic Precipitator

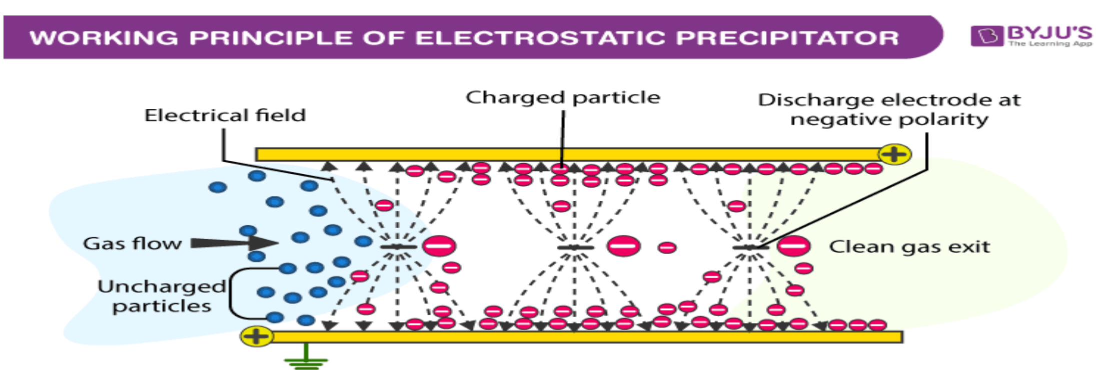
An electrostatic precipitator (ESP) is defined as a filtration device that is used to remove fine particles like smoke and fine dust from the flowing gas. It is the most commonly used device for air pollution control. They are used in industries like steel plants, and thermal energy plants.

In 1907, chemistry professor Frederick Gardner Cottrell patented the first electrostatic precipitator used to collect sulphuric acid mist and lead oxide fumes emitted from various acid-making and smelting activities.



2.4.1. Working Principle of Electrostatic Precipitator

The working principle of the electrostatic precipitator is moderately simple. It consists of two sets of electrodes: positive and negative. The negative electrodes are in the form of a wire mesh, and the positive electrodes are plates. These electrodes are vertically placed and are alternate to each other.



The gas borne particles such as ash are ionized by the high voltage discharge electrode by the corona effect. These particles are ionized to a negative charge and are attracted to positively charged collector plates.

The negative terminal of the high voltage DC source is used to connect the negative electrodes, and the positive terminal of the DC source is used to connect the positive plates. To ionize the medium between the negative and the positive electrode, a certain distance is maintained between the positive, negative electrode and the DC source resulting in a high voltage gradient.

The medium that is used between the two electrodes is air. There might be corona discharge around the electrode rods or the wire mesh due to the high negativity of negative charges. The entire system is enclosed in a metallic container containing an inlet for flue gases and an outlet for filtered gases. There are plenty of free electrons as the electrodes are ionized, which interact with the dust particles of the gas, making them negatively charged. These particles move towards positive electrodes and fall off due to gravitational force. The flue gas is free from the dust particles as it flows through the electrostatic precipitator and is discharged to the atmosphere through the chimney.

2.4.2. Electrostatic Precipitator Applications

A few noteworthy electrostatic precipitator applications are listed below:

- Two-stage plate ESPs are used in the engine rooms of shipboard as the gearbox produces explosive oil mist. The collected oil is reused in a gear lubricating system.
- Dry ESPs are used in thermal plants to clean the air in ventilation and air conditioning systems.
- They find applications in the medical field for the removal of bacteria and fungus.
- They are used in zirconium sand for detaching the rutile in plants.
- They are used in metallurgical industries to clean the blast.

2.5. Laser printing

Laser printers use the xerographic process to make high-quality images on paper, employing a laser to produce an image on the photoconducting drum. In its most common application, the laser printer receives output from a computer, and it can achieve high-quality output because of the precision with which laser light can be controlled. Many laser printers do significant information processing, such as making sophisticated letters or fonts, and may contain a computer more powerful than the one giving them the raw data to be printed.

2.5.1. Printing process

2.5.1.1. Sending

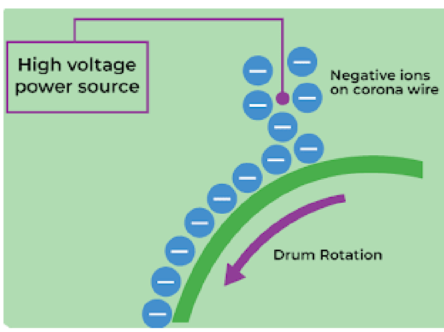
To begin the laser printer process, the document is broken down into digital data and sent from the respective computer to the printer.

In a feat of binary wizardry, printers reassemble this computer data into a printed image. Laser printers will capture the data and process the digital document.

2.5.1.2. Cleaning

Laser printers leave a residue on the printer drum. Cleaning is a physical and electrical process carried out in order to remove the previous print job and prepare the photosensitive drum for the new print job. During the cleaning process, remnants of toner on the drum are scraped away by a rubber-cleaning blade into a debris cavity. Electrical charges remaining on the drum from the prior print job are defused by electrostatic erase lamps inside laser printers. Lubrication is then applied to the heat roller in order to make sure an adequate amount of heat is evenly applied to transfer the incoming image.
Conditioning

The process called conditioning involves applying a charge to the drum unit and the paper as it passes through the corona wire. Adding a static charge to the paper allows an image to be electrostatically transferred to the laser printer page.



The primary charge roller springs to life, spinning the adjacent organic photoconductor (OPC) drum. Ions on the corona wire coat the drum with static electricity. The electro-photographic process begins at the molecular level. The drum completes its revolution, slathered with a negative charge.

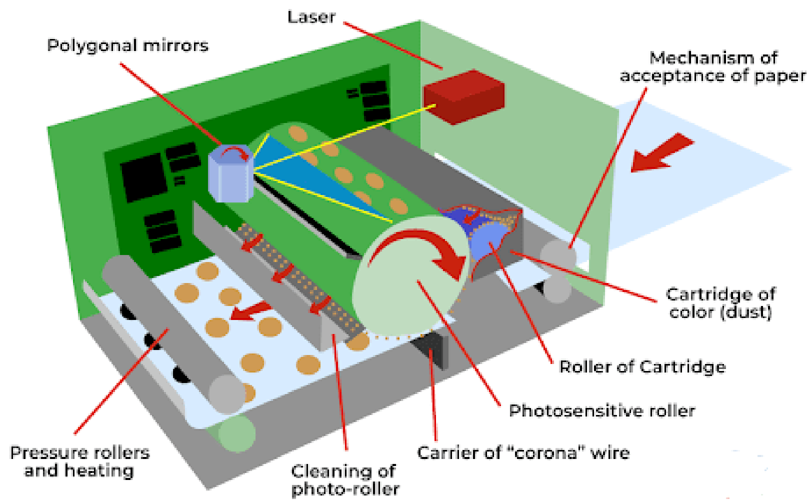
2.5.1.3. Exposing

Laser time! The next step is exposing. Here, the photosensitive drum is exposed to a laser beam. Every area of the drum exposed to the laser has its surface charge reduced to about 100 volts DC.

An invisible latent print is generated as the printer's drum turns. The image that will ultimately be printed exists for the first time as a thin layer of electrons on the OPC drum.

The darkness within the printer cartridge is broken by the glow of the laser. The beam bounces off a spinning, multi-sided mirror and breaks into countless rays of information, spraying the OPC drum with its knowledge, turning the negative charges positive.

Line-by-line, the laser speaks to the revolving surface of the drum unit, describing a page with the language of charged toner particles. This part is black, this part is yellow, and this part...yes, this part...is wonderfully magenta. The drum wears a positively charged image on its surface, ready to transfer onto the paper.



2.5.1.4. Developing

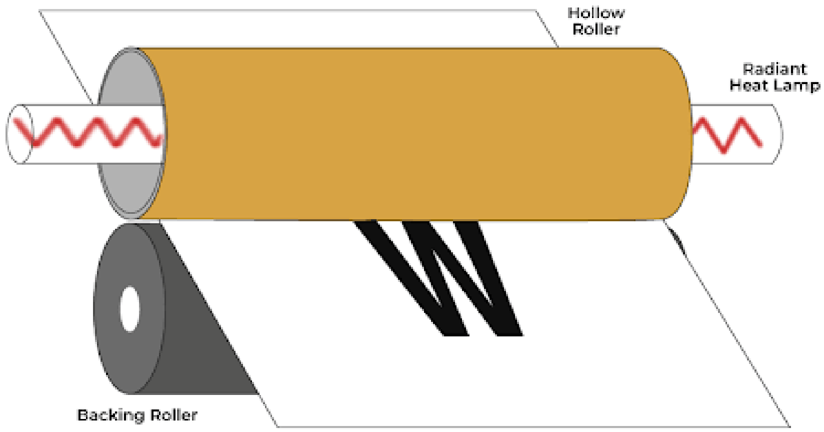
In the developing stage, toner is applied to the latent image on the drum. Toner is composed of negatively charged powdered plastics — black, cyan, magenta, and yellow. The drum is held at a microscopic distance from the toner by a control blade.

Toner is 85-95% finely ground plastic. Other toner ingredients used in printers include colored pigments, fumed silica, and control agents.
Silica keeps the toner particles from clumping and sticking together. It also helps the toner flow smoothly from the cartridge to the printer. Bits of zinc, iron, and chromium are used as control agents to retain the negative electrostatic charge of the toner particles.

A variety of pigments are used to create colored printer toner cartridges.

The following pigments used are:

- Yellow. Pigment yellow 180, composed of a Benzimidazole.
- Magenta. Pigment red 122, composed of 2,9-Dimethyl-Quinacridone.
- Cyan. Pigment blue 15:3, composed of Copper Phthalocyanine.
- Black laser toners still contain carbon black powder, as in early laser toner models, combined with powdered plastic.



2.5.1.5. *Transferring*

Next comes transferring. The secondary corona wire, or transfer roller, applies a positive charge onto the paper. The agitator unit inside the toner cartridge hopper spins, and the toner begins to heat up.

The toner adder spins, pulling toner in, gathering toner dust on its surface. A doctor blade sweeps over the adjacent developer roller, leveling the toner to a precise height.

All the spinning and commotion has left the magenta particles on its surface with a negative charge, and when it comes in contact with the positively charged image on the OPC drum, the laws of attraction take over. The negatively charged toner on the surface of the drum is magnetically attracted to the positively charged areas on the paper.

The magenta toner particles are pulled from the developer onto the drum according to the precise instructions left by the laser. A few magenta toner particles here, several there, and a bunch more that will blend with black, yellow, and blue to form a rainbow of beautiful colors.

The sheet of paper passes over each color cartridge -- magenta, yellow, cyan, and finally black — as the image is transferred onto the paper.

2.5.1.6. Fusing

The final phase is fusing. Heat and pressure are applied to the toner by the fuser unit. The toner generates a permanent bond as it is pressed and melted into the paper. Teflon covers the fuser unit as light silicon oil is applied in order to remove any possibility of the sheet of paper sticking to them.

The fuser unit essentially melts the toner powder onto the page, creating the image. A wiper blade cleans any remaining particles off the OPC drum and deposits them into a waste bin. Any latent charge left on areas of the drum surface is erased, restored, refreshed, and ready for the laser printer to sing again.

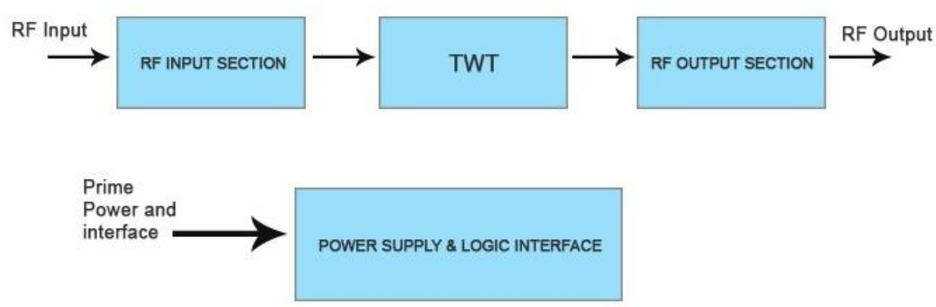
Excess toner not transferred to the OPC drum is scrubbed from the developer unit and returned to the hopper to be used again on the next printed page. Toner that remains on the OPC drum and not transferred is wiped into a waste toner bin.

2.6. TWT Amplifier

A Traveling-Wave Tube or TWT Amplifier is a high power, high-frequency amplifier that is built using traveling wave tubes. A traveling-wave tube is a type of vacuum tube used to amplify high-frequency signals. The RF signal is amplified by absorbing power from a beam of electrons as it goes through the tube.

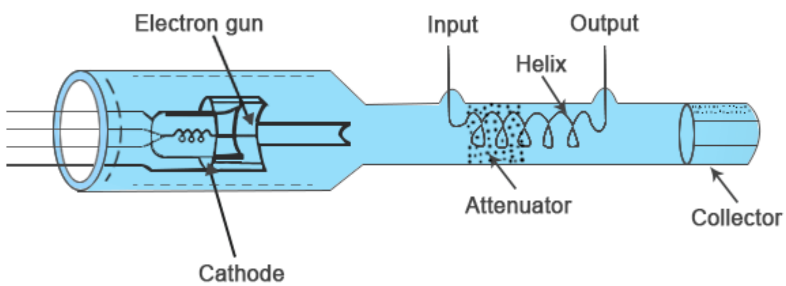
TWTAs usually operate from 300 MHz up to frequencies over 100 GHz (there are cases where these go as high as 650 GHz). They provide power levels from a few watts to megawatts with a gain of 40 to 60 dB.

A typical TWT Amplifier consists of a traveling wave tube, an RF input section, a power supply & logic interface section, and an RF output section. The TWT is the part that is responsible for the amplification of the signal.



Block Diagram of a TWTA

The TWT consists of an electron gun (composed of a cathode, a control or modulating grid, and an accelerator), an RF circuit (delay line), an attenuator and a collector.



Physical construction of TWT

The cathode produces an electron beam, which is slower than the speed of light, and is focused into a tight beam using magnetic field along the axis of the tube. The speed of electron beam in a TWT amplifier is generally 10 to 50 % of speed of light and it depends on the cathode voltage.

The RF signal, however, propagates at the speed of light and there must be a mechanism to slow down its speed to permit interaction between the beam and the signal. This slowdown is achieved by using a slow wave structure, which is usually a helix, and the slowed down RF signal is called the slow wave. The attenuator isolates the input and output sections to prevent oscillations. The velocity of the electron beam, traveling through the helix, induces/adds energy to the RF waves on the helix, thus amplifying the signal.

2.7. To monitor the physiological state

Electric fields can be applied to monitor the physiological state of tissues for diagnostic purposes. All materials, including tissue, have an associated resistance, R, and capacitance, C. If an AC voltage is applied to tissue, current that depends on both R and C will flow through the tissue. Capacitances restrict the flow of low frequency current, but allow high frequency currents to pass. The value of C determines the transition frequency range for passage and blockage of the AC current. For tissues that frequency is around 100 kHz–1 MHz.

The Figure below depicts the Fricke circuit model commonly used for tissue. Re and Ri represent, respectively, the resistances of the extracellular and intracellular resistances. Both resistances are determined primarily by water content. C represents the capacitance of the cell membrane. Low frequency currents are blocked by C from the cell interior and thus serve as a measure of extracellular water. C allows high frequency currents to enter the cell interior and thus measure the combination of Re and Ri. Use of two frequencies allows the separation of Re and Ri and thus the determination of intracellular and extracellular water content.

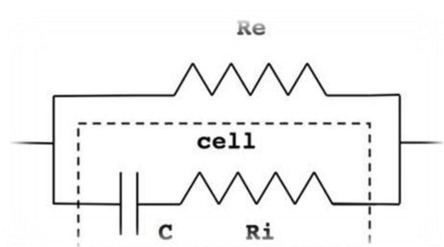


Figure: Fricke circuit model.

These principles can be used for the measurement of body composition. In healthy individuals there is a well-defined relationship between total body fat-free mass and the total body water mass. Knowledge of the total body fat-free mass and the total body mass yields the body's fat mass and thus the percentage body fat. Depending on the positions of the electrodes, this method can be used for measurements on the whole body or on specific limbs. Determination of changes in the ratio of Re to Ri can yield information regarding the possibility of fluid leakage (edema) into a limb.

A different application of the Fricke model is useful in the monitoring of breathing. The air in the lungs does not permit the flow of current and can be modeled as a time-varying C. Measurement of the current over time yields the breathing rate and thus serves as a monitor of sleep apnea. How R and C vary over a wide range of frequencies could be used to differentiate healthy tissue from diseased tissue. The sensitivity of devices that identify breast tumors is not yet sufficient to receive governmental approval. For a detailed review of the various diagnostic uses of electric fields see the review by Hart.

Electrostatics has an important role in the field of medicine. Anodes, cathodes, and electric potential sources are heavily relied upon in X-RAY machines, heart-rate monitors, electrostatic therapy, protein modeling, and a plethora of devices used in hospitals and clinics. The fundamental aspects of electrostatics are often applied to a variety of physician practices, and they are currently being explored by a biomedical engineering research team interested in developing a new device involved in pain management.

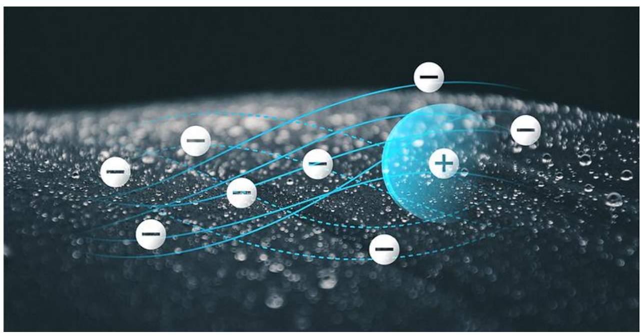
2.8. In Heart rate monitor

A heart rate monitor (HRM) is described that includes an electrostatic discharge protective layer configured to at least partially shield the heart rate monitor from electrostatic discharge (ESD). In one or more implementations, the heart rate monitor includes a strap configured to be worn on the body (e.g., about the torso) of a user. Signal and ground electrodes are disposed at least partially on (e.g., extend along) the inner surface of the strap. The signal electrode is configured to receive electrical impulses from the heart of the user, while the ground electrode is configured to electrically ground the heart rate monitor (HRM) to the body of the user. An electrostatic discharge protective layer is disposed in the strap over the signal electrode so that the signal electrode is at least substantially positioned between the body (e.g., the torso) of the user and the electrostatic discharge protective layer when the strap is worn (e.g., about the torso). The electrostatic discharge protective layer may be electrically coupled to the ground electrode or a connector of the heart rate monitor to at least partially shield the signal electrode from electrostatic discharge. In one or more embodiments, the electrostatic discharge protective layer comprises an extension of the ground electrode over the signal electrode. In other embodiments, the electrostatic discharge protective layer comprises a separate conductive layer that is coupled to the ground electrode so that the ground electrode extends from beneath the conductive layer.

2.9. Electrostatic Disinfection

Electrostatic spray surface cleaning is the process of spraying an electrostatically charged mist onto surfaces and objects. Electrostatic spray uses a specialized solution that is combined with air and atomized by an electrode inside the sprayer. Subsequently, the spray contains positively charged particles that are able to aggressively adhere to surfaces and objects. Because the particles in the spray are positively charged, they cling to and coat any surface they're aimed at.

For awkwardly shaped objects or hard to reach places, cleaning staff only have to point and spray; the nature of the mist allows it to coat surfaces evenly, and envelope objects—even if the mist is only sprayed from one side. After the spray is applied, the sanitizing agent works to disinfect the covered surfaces. For this reason, electrostatic spray is an excellent solution for germ and contaminant ridden areas.



Electrostatic spray is electrically charged, allowing the appropriate sanitizers, mold preventatives and disinfectants to wrap around and evenly coat all types of surfaces for a more complete clean. As the chemical exits the electrostatic sprayer, it's given a positive electrical charge. The droplets then become attracted to all negative surfaces, covering the visible area, underside and backside, with the sanitizing agent. Surfaces that are already covered will repel the spray, making the method extremely efficient.

2.10. Electrostatic treatment of bean seeds

The classical methods of seed treatment make use of chemical substances which are either expensive or harmful to the soil. This paper demonstrates that exposure to the action of a high-intensity electric field can be an effective substitute for the chemical agents. The experiments were carried out on bean seeds (Phaseolus vulgare), naturally infected with Colletotrichum lindemuthianum. Under normal conditions, only about 30% of a reference sample of such seeds germinated. Other samples were subjected to 50 Hz electric fields ranging from 2-16 kV/cm with exposure time ranging from 1 to 30 s. In the optimum laboratory test, more than 99% of the seeds germinated. The weight of the resulting bean plants was significantly greater than those grown from nontreated seeds. The field tests proved the efficiency of this method, which could be successfully employed for the prevention or treatment of various seed-transmitted diseases of plants. Ozone generation by partial discharges between seeds seems to be the main sterilizing agent, while the activation of OH radicals under the action of the high-intensity electric field may explain the intensification of the biological processes.

2.11. Electrostatic Oscillation Therapy

Deep oscillation is a unique, patented and non-invasive treatment method which uses an oscillating electrostatic field. Biologically effective oscillations penetrate the treated tissues as deep as 8 cm. The deep vibrating or pumping effect is created by moving the hand-held applicator above the tissue. Compared to other procedures, deep oscillation not only feels pleasant to the patient but is also effective on all types of tissue (skin, connective tissue, muscles and blood vessels). The treatment is carried out using a hand-held applicator and a titanium element or gloves and an electric stimulation electrode.

Deep oscillation is used:

- to reduce pain (severe trauma-related pain as well as chronic pain, such as backache, muscle and joint pain);
- to reduce inflammation;
- to reduce swelling (bruising, hematomas, sprains, oedemas);
- after surgery (endoprosthesis, lymphostasis, osteosynthesis etc.);
- to promote wound healing

2.12. In X-ray imaging

An x-ray examination creates images of your internal organs or bones to help diagnose conditions or injuries. A special machine emits (puts out) a small amount of ionising radiation. This radiation passes through your body and is captured on a special device to produce the image.

The dose of radiation you will receive depends on the area of your body being examined. Smaller areas such as the hand receive a lesser dose compared to a larger area such as the spine. On average, the dose of radiation is roughly the same as you would receive from the general environment in about one week.

A small amount of ionising radiation is passed through the body. In the past, this went onto a sheet of special film. Nowadays x-ray examinations are more likely to use a device that will capture transmitted x-rays to createan electronic image.

The calcium in bones blocks the passage of radiation, so healthy bones show up as white or grey. On the other hand, radiation passes easily through air spaces, so healthy lungs appear black.

As we all know we use electrostatic to produce X-ray radiation


3. Summary

Electrostatic induction was used in the past to build high-voltage generators known as influence machines. The main component that emerged in these times is the capacitor. Electrostatic induction is also used for electro-mechanic precipitation or projection. In such technologies, charged particles of small sizes are collected or deposited intentionally on surfaces. Applications range from electrostatic precipitator to electrostatic coating and inkjet printing.

Electrostatic actuators have recently been attracting interest in the medicine area. Electrostatic actuators can be used to relive pain. Other relevant applications include helping in seed(bean) germinating and also used as disinfector.

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