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Demonstration

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Hydroglyphics: Demonstration of Selective Wetting on Hydrophilic and Hydrophobic Surfaces

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Supporting Information

ABSTRACT: A visual demonstration of the difference between hydrophilic and hydrophobic surfaces has been developed. It involves placing a shadow mask on an optically clear hydrophobic plastic dish, corona treating the surface with a modified Tesla coil, removing the shadow mask, and visualizing the otherwise invisible message or pattern by applying water, thus entitled as hydroglyphics.

KEYWORDS: *General Public, Elementary/Middle School Science, High School/Introductory Chemistry, First-Year Undergraduate/General, Demonstrations, Public Understanding/Outreach, Hands-On Learning/Manipulatives, Nanotechnology, Physical Properties, Surface Science*

Hydrophilicity and hydrophobicity are important concepts for understanding the wetting and adhesion characteristics of a solid substrate.[1−3] Many plastic surfaces that are structurally homogeneous and inert, such as polyethylene bottles and polystyrene cups and dishes, can have low surface energy. They exhibit nonwetting properties to many printing inks, coating materials, and adhesives.[4] In particular, the nonpolar nature of these surfaces is hydrophobic (Figure 1A), that is, water droplets tend to ball up with a high contact angle on the surface.[5] Corona treatment is a widely adopted inexpensive process in the polymer film manufacturing industry for modifying the surface properties to improve adhesion and printability of plastic sheets or laminated films. During the corona treatment process, the electrical energy is converted to light (purple glowing arcs), sound (zapping noise), and heat. Accelerated electrons break up the polymer chains and gas molecules in the air (e.g., oxygen), are ionized (cold plasma), and react with the surface of nonpolar material to create more polar, higher surface energy, oxygenated material (Figure 1B).[6,7] This process activates the surface to be more adhesive and allows for bonding to other materials to reduce the surface energy. As a result, a nonwetting plastic surface can be converted to a wetting surface: water droplets tend to wet and spread well with a low contact angle, commonly described as hydrophilic.

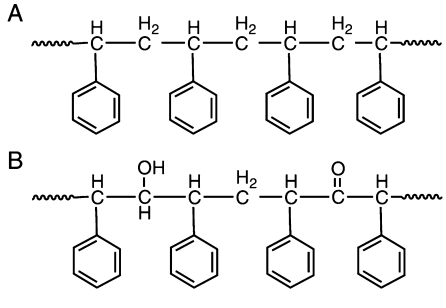

Figure 1. Proposed chemical structure of (A) untreated polystyrene and (B) corona-treated polystyrene. Note that hydrophilic groups such as −OH and C═O have been inserted due to the reaction with corona-activated oxygen in air.[6]

The demonstration utilizes a corona treatment method on an optically clear polystyrene Petri dish and visualizes this effect by applying water. Corona treating a Petri dish that has areas covered with thick stickers (e.g., letters, numbers, or shapes) converts hydrophobic surfaces to hydrophilic only on the unmasked areas. When the stickers are removed, the Petri dish still appears optically clear. Electron micrographs do not reveal a difference in the treated and untreated surfaces. However, due to the increased contrast in the hydrophobic masked areas, and hydrophilic unmasked areas, the invisible encrypted message can be visualized by applying water (e.g., spraying water or breathing). Because the encrypted messages are created from water, this demonstration is called "hydroglyphics" (a combined word of hydro- meaning water and the Egyptian writing system hieroglyphics).

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MATERIALS AND APPARATUS

- Modified Tesla coil (0.35 A, 110 V)[8]
- A wire mesh head, a Cu wire, and an electrical tape or aluminum tape
- Large stand and clamp (to hold the modified Tesla coil)
- Power strip or timer with an on−off switch
- Petri dishes (unsterilized or EO gas sterilized, 60 mm diameter)[9]
- Thickers stickers (can be replaced by electrical tape)[10]
- Stopwatch or timer
- Squirt bottle
- Spray bottle
- Large tray (for collecting waste water)
- Paper towel
- Al foil (to cover a 60 mm Petri dish or any similar object)
- Tweezers
- Disposable pipette
- Food colorant (optional)
- Earplugs (optional)

SUMMARY OF THE DEMONSTRATION

The demonstration consists of five steps: (i) comparing wetting properties of untreated and corona-treated Petri dishes; (ii) creating a design for hydroglyphics using a shadow mask; (iii) corona treatment; (iv) removal of the shadow mask; and (v) visualization of the hydroglyphics. The demonstration takes 5−10 min per individual Petri dish.

DETAILS OF THE DEMONSTRATION

Modification of a Tesla Coil

A 15−20 cm piece of 16 gauge copper wire (the optimum wire gauge may be different for different Tesla coils) was cut and bent into a 1−1.5 cm diameter loop in the middle of the wire (Figure 2A). A 5 cm diameter circular piece of a metal wire mesh screen was cut and attached to the copper wire with electrical or aluminum tape over the loop to ensure that a good electrical connection is made. The wire mesh electrode should not have a sharp edge as this tends to focus the arc on one area and leads to deformation and burning of the Petri dish. With the power off, the end of copper wire was inserted into the Tesla coil or was attached to the tip of the Tesla coil with tape. The Tesla coil was mounted vertically using a stand clamp as shown in Figure 2B.

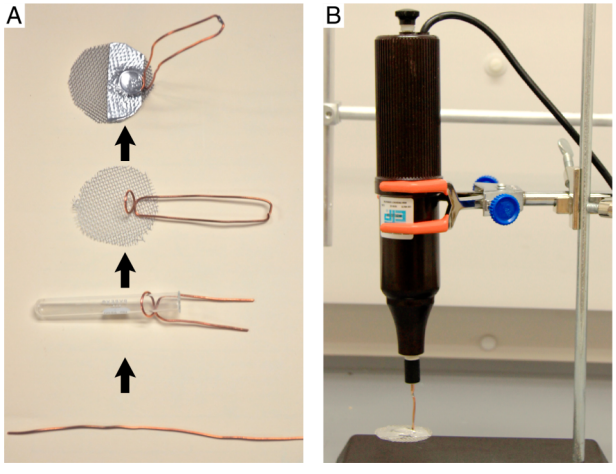

Figure 2. Modified Tesla coil: (A) procedure for making a loop electrode and a wire mesh electrode attached to a loop electrode and (B) a modified Tesla coil mounted on a stand.

Choice of Petri Dish

Nonsterilized Petri dishes are ideal for this demonstration. Gamma irradiation or EO gas-sterilized Petri dishes can also be used in this demonstration. However, electron-beam or plasma-treated Petri dishes are hydrophilic and cannot be used.

Choice of Stickers, Alternative Options

The shadow mask should block the air plasma from reacting with the masked area. Any flat, smooth-surfaced, soft, rubber-like materials can be used as a shadow mask in place of stickers. If a sheet of such material is available, custom shapes can be created by cutting it. However, films that are too thin are not easy to remove after corona treatment.

Starting the Interaction with the Students

The demonstration was started by asking students to compare the difference between an untreated Petri dish (hydrophobic) and a corona-treated Petri dish (hydrophilic) when water droplets are placed in them. After the students noticed the difference between the two surfaces, a 60 or 110 mm diameter untreated Petri dish was given to each student (Figure 3A) and they were asked to create their own hydroglyphics design (e.g., their initials or favorite number) by placing alphanumeric Thickers foam stickers inside their Petri dish (Figure 3B).

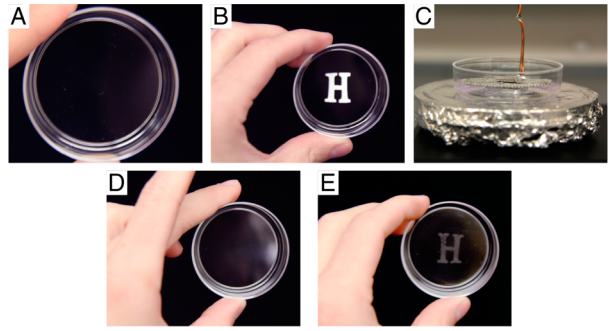

Figure 3. Step-by-step procedure for creating a letter H in hydroglyphics: (A) an untreated 60 mm Petri dish, (B) a sticker mask attached to the Petri dish, (C) corona treatment using a modified Tesla coil, (D) after removal of the sticker, and (E) a letter H is visualized by breathing method.

Inspecting the Stickers for Best Results before Corona Discharge

After receiving the Petri dish with the student letters, the instructors made sure that the masks adhere to the Petri dish with no visible air gaps when checked from the backside of the Petri dish. The Petri dish was then placed on a metal or other conductive surface grounded to create a uniform corona treatment. For example, the Petri dish could be placed on top of aluminum foil or on a second Petri dish wrapped by aluminum foil.

Corona Treatment

The modified Tesla coil with the wire mesh electrode was placed to cover the inner area of the Petri dish. The wire mesh electrode was kept roughly 3−4 mm above the surface of the foam stickers and horizontally as shown in Figure 3C, which gave the best results. A uniform and vertical arc gave the best contrast. The corona treatment was carried out for ∼15 s by

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turning the Tesla coil on from a remote switch. The Tesla coil was turned off and the Petri dish was turned 180° and the second corona treatment was carried out for ∼15 s. This ensured a uniform corona treatment but the optimum treatment time may vary for different Tesla coils and the size of the Petri dishes. Alternatively, a small (∼15 mm diameter) wire looped electrode can be scanned inside a 60 mm Petri dish for about 20−30 s by hand. In general, scanning a small loop-shaped wire electrode inside a Petri dish gave reproducibly better results than a stationary wire mesh electrode, but it may not be suitable for a younger audience. The corona treatment time should be optimized for each modified Tesla coil. In addition, more than one Tesla coil should be used if the demonstration is intended for a large group.

The hydroglyphics demonstration can also be done over a large area. For this, a hand-held wire-terminated or brush-terminated Tesla coil was used to create a curtain of corona that is ideal for treating a large area by scanning. For example, about 1−2 min of uniform scanning over the entire area of a 150 mm Petri dish was sufficient to create the effect.

Removal of Stickers

After removing the Petri dish from the corona treatment setup, the stickers were carefully removed with tweezers or a gloved hand to avoid contamination of the surface with grease from fingers. A few sets of tweezers were necessary when demonstrating for a large audience, as this step was the slowest step.

Visualization of Hydroglyphics

The Petri dish was optically clear (Figure 3D), but the message appeared when water was applied (Figure 3E). This can be done by applying warm breath on the treated surface, misting water, or by carefully applying water using a pipette or squirt bottle as shown in Figure 4. The easiest way to visualize hydroglyphics was to breathe on the Petri dish. The instructors usually made their own hydroglyphics sample and showed the students how to visualize the message by breathing method. The next easiest method was using a spray. With some practice, the message was visualized by applying water from a squirt bottle. The water did not wet on the masked areas making a good hydroglyphics. However, students tended to apply more water than what was needed to increase the contrast, only to find that the water went everywhere and the message was lost. In this case, the excess water was poured off and the Petri dish was left to dry. The drying of water took place faster on hydrophobic surface than hydrophilic surface; thus, it created a good contrast to show the message again. Alternatively, the Petri dish with water can be held above a table and the shadow of hydroglyphics was seen if the contrast is not adequate in actual Petri dish. Addition of some food colorant to the water allowed for creating colored hydroglyphics.

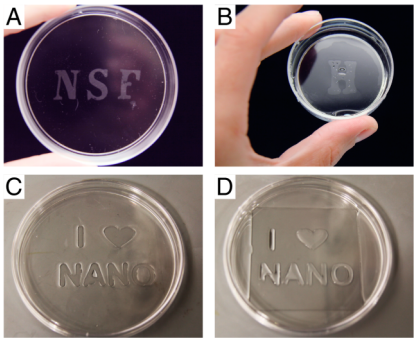

Figure 4. Visualization methods of hydroglyphics messages: (A) breathing method, (B) spraying water, (C and D) application of water. The shadow masks used for (C) and (D) have different tones.

The message disappeared when the Petri dish was dry or when too much water was applied to cover the whole area inside the Petri dish. Drying the dish with a towel corrupted the treated surface. Students asked to keep their Petri dish and were provided with a cover to keep their hydroglyphics free from dust or smudging by touching it. If properly stored, the encrypted message lasted for over a month.

HAZARDS

The demonstration should be performed in a well-ventilated area (e.g., inside a chemical hood or in a large room with good ventilation) as the corona treatment process creates ozone. When the demonstration is carried out in a large hall, a small battery-powered electric fan next to each Tesla coil can quickly dissipate local accumulation of ozone. Prolonged exposure to a high dose of ozone can lead to light headache.[11] Some people may be very sensitive to ozone and it can aggravate pre-existing medical conditions (e.g., asthma[12]). The electric arc from the Tesla coil will find a conductive path toward an electrical ground. If someone is touching an electrically conductive object (e.g., painted metal such as the bottom stand or if the table on which this demonstration is carried out is made of metal) or touching an object too close to the Petri dish being treated, the person may get an electric shock. However, since the current is negligibly small, generally there is no serious harm. The corona treatment step may create some noise depending on the shape and size of the wire mesh electrode and can be irritating to some people. Overtreatment of the Petri dish with corona causes heating and may lead to deformation, melting, or burning of Petri dish, which may emit hazardous gases.

CONCLUSION

The hydroglyphics demonstration is appropriate for all levels. The middle school and younger age groups were "wowed" by seeing their initials. One student said the hydrophobic state "was like waxing Dad's car". Older students (to the graduate level) were also impressed and could understand the reasons for it. Students tend to make more than one hydroglyphic sample and wanted to keep them to show this effect to their friends and parents later. Some students wanted to learn more details for what is actually happening with the corona treatment.

ASSOCIATED CONTENT

Supporting Information

A movie of this demonstration in mp4 format (zip file). This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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