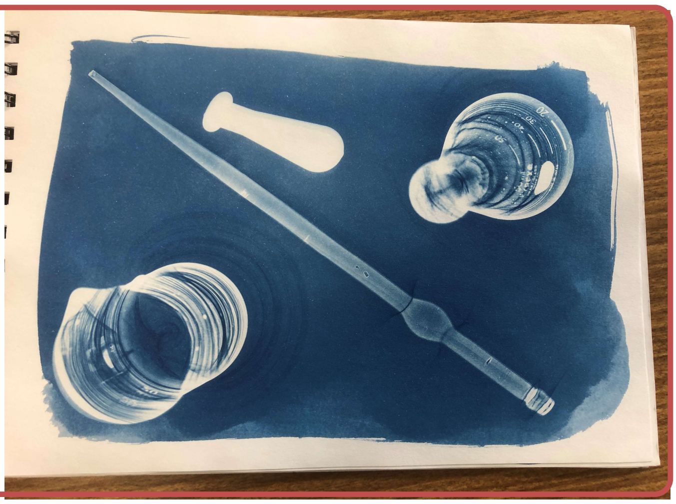

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Determination of the Degree of Ultraviolet Inhibition with Cyanotype

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Abstract

We capture photographs to convert valuable moments into distinguishable memories. Photographs can be easily printed today, however, this process was remarkably different at the time of their discovery. The cyanotype, known as the blueprint process, forms the origin of photographs and was first invented by the English scientist John Frederick William Herschel in 1842. The photographers did not use this methodology owing to its distinctive colors. However, it was extensively utilized to create mathematical or constructional drawings due to several advantages over the previously used silver method in terms of cost, durability, and safety. Electron transfer between iron ions leads to the appearance of a blue color, and light is used as a catalyst for creating different valences. An image with gradation forms as a colored film, which suppresses light-induced changes due to light absorption at 300–400 nm[1] wavelengths. The areas covered by the colored films are light blue than the uncovered or white areas because the film prevents the conversion of iron (III) into iron (II). The paper is washed with water to remove unreacted yellow iron (III), and photographs are obtained with blue gradation. We use various materials to intercept light and observe the differences depending on the shading material.

Introduction

The cyanotype forms the origin of pictures, and its uniqueness stems from using UV light during the printing process. Cyanotype is based on a mechanism that quantifies the amount of ultraviolet (UV) light transmitted through a material. This mechanism can be used as a tool to design materials that limit UV exposure and their associated risks. Overexposure to UV radiation causes severe health issues, such as sunburn, erythema, photodamage, photocarcinogenesis, and eye damage[2]. The production and use of plastics have remarkably increased in recent decades owing to their accessibility and applicability; thus, plastic disposal has become a major challenge. The amount of plastic in the ocean is expected to exceed the quantity of fish consumed by 2050. According to the Japan Meteorological Agency[3], the amount of UV rays reaching Tsukuba city in Japan increases annually. We found that some sunscreens contain microplastics. Therefore, light transmittance through these plastics is possible. Such a possibility could increase the risks[4] associated with UV exposure owing to the continuous increase in the annual amount of radiation and the use of plastics. We conducted experiments to identify the wavelengths that specifically caused the reaction by transmitting light through various colored films and proposed the fabrication of high-performance UV protection tools by investigating colors with lower transmittance. This study aims to find a potential solution to contemporary plastic-related issues, using the traditional blueprinting method.

Materials and Methods

Materials

1. Spectroscopic charge-coupled device (CCD)
2. Fiber patch cords
3. Ultraviolet radiator
4. Tungsten halogen light source
5. Potassium hexacyanoferrate (III)
6. Ferric ammonium citrate
7. Citric acid
8. Beaker (50 mL)
9. Graduated cylinder
10. Dispensing spoon
11. Brush
12. Prism lens
13. Stand
14. Pipette
15. Clamp
16. Plastic tray
17. Glass rod

Methods

Part 1 Cyanotype Creation

1. Steps 1–3 were conducted in a darkroom. Potassium hexacyanoferrate[5] (III) (0.50 g), ferric ammonium citrate[6] (1.0 g), and distilled water (20.0 mL) were placed in a beaker using dispensing spoons, and mix the chemicals with glass rod.

2. The chemicals were passed through filter paper using a brush to ensure even distribution.

3. The chemically impregnated filter paper was exposed to UV light using UV lamps or sunlight. When UV light was intercepted by the plastic, the material was taped onto paper to cover it. Colored overhead projector (OHP) sheets were used to intercept the UV light with colored films, as shown in Figures 1 and 2.

4. Distilled water (500.0 mL) and citric acid (5.0 mL) were placed in a plastic tray to prevent unwanted reactions that can occur in a metal tray.

5. The filter paper in Step 3 was dipped into the solution in the plastic tray to wash away the unreacted chemicals.

6. The paper was washed with distilled water.

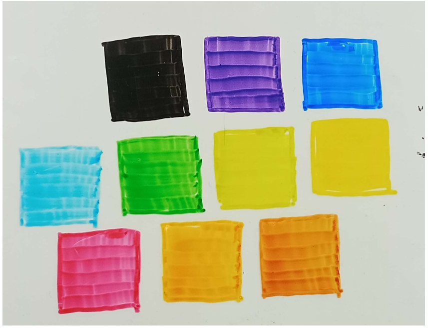

Figure 1. OHP sheet colored with water-based pigments.

Figure 2. OHP sheet colored with oil-based dyes.

Part 2 Spectroscopic Studies of Light Transmitted Through Filter Paper After Reaction

1. The lights were turned off, and the curtain was closed to prevent UV light from affecting the measurement.
2. CCD X-ray detectors, fiber cords, a tungsten halogen light source, a computer for obtaining the spectrum, a prism lens, and stands were assembled, as shown in Figure 3 and 4.

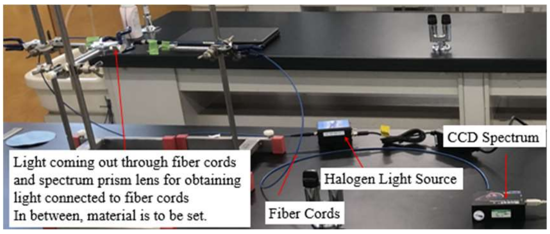

Figure 3. Experimental setup using fiber cords, tungsten halogen light source, CCD, prism lens, and stands.

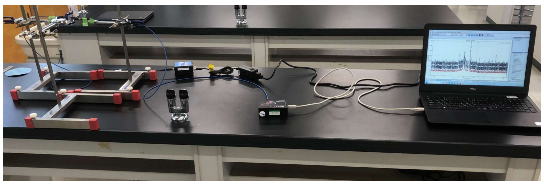

Figure 4. Image of the entire setup for measurement

3. The filter paper was secured on a stand using a clamp to measure light transmittance.
4. The computer program for obtaining spectrum data (BWspec) was launched.

Equations and chemical formulae

The reaction depicted in Figure 5 is performed in this experiment.

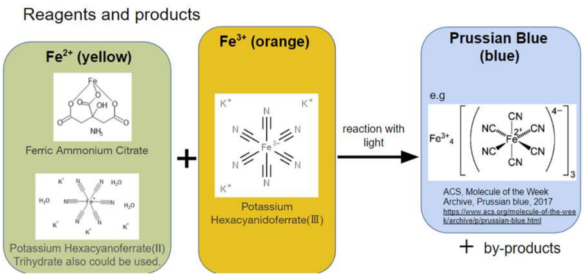

Figure 5. Chemical formulae for cyanotype with chemicals and their images.

Results and Discussion

UV Light Transmittance of Plastics

The blue color of the filter paper darkened as more reactions occurred, indicating that the intercept material exhibited a higher UV light transmittance. Lower UV light transmittance was associated with higher peak intensity. Polypropylene (PP) exhibits the highest UV radiation transmittance, followed by polyvinylidene chloride (PVDC), polystyrene (PS), polyethylene (PE), polyethylene terephthalate (PET), and high-density polyethylene (HDPE) (Figure 6). Differences are observed at the highest relative intensity, which is approximately 614 nm for polypropylene, polyvinylidene chloride, and high-density polyethylene, and 271 nm for the other materials.

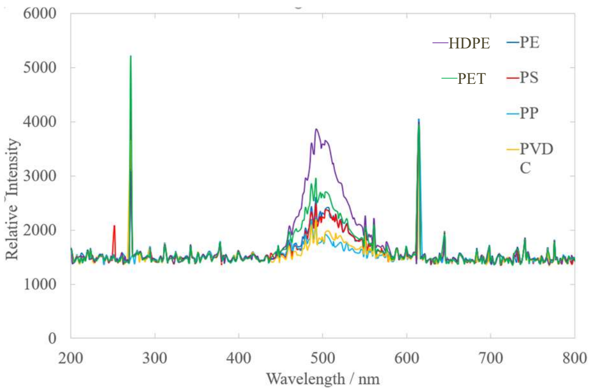

Figure 6. Spectra obtained through the filter papers with BWspec, where UV light was intercepted by plastic.

This reaction is promoted by the UV radiation that originates from the sun and constitutes our daily UV radiation exposure. We are exposed to two types of UV radiation in our daily lives: ultraviolet A (UVA) and ultraviolet B (UVB). UVA has a wavelength of 320–400 nm and promotes skin cell aging, whereas UVB has a wavelength of 280–320 nm and causes sunburns owing to its higher energy. This experiment used radiation with wavelengths between 300–400 nm[7], which enabled the observation of UVA inhibition. With the increasing amount of UV radiation, the risk of skin cancer and other adverse effects of UV radiation are expected to increase over the years. These data would be valuable for developing UV protection tools.

UV Light Transmittance of Colored OHP Films

Figure 7 indicates a minimal reaction for the OHP film with black pigment, followed by light green, purple, blue, and no pigment. The spectrum from the black film appears as an outlier but indicates the prevention of nearly all UV light. Figure 8 reveals that the minimal reaction occurs with the black film, followed by the light-green, non-colored, blue, and purple films.

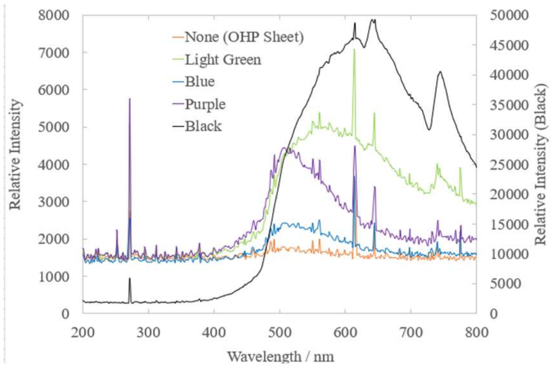

Figure 7. Spectra obtained through the filter papers with BWspec, where UV light was intercepted by an OHP film colored with water-based pigment.

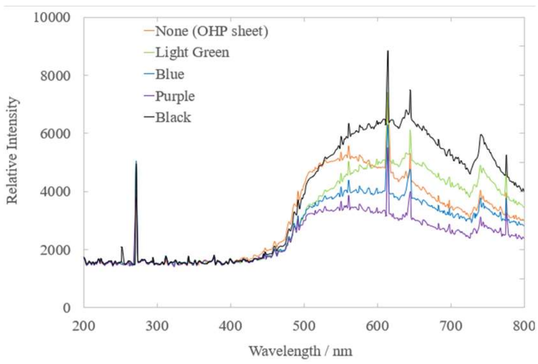

Figure 8. Spectra obtained through the filter papers with BWspec, where UV light was intercepted by an OHP film colored with oil-based dye.

A strong response is observed when radiation with short wavelengths (such as violet and blue light) are transmitted, indicating that shorter wavelengths have a considerable effect on the response, as described in the Introduction.

The peaks in the spectra in figure 7 and 8 are different, and the relative intensities for the films with the dye are higher than those for the films with the pigment, which could be attributed to their respective structures. Dyes are soluble, transparent, and do not scatter light, whereas pigments are insoluble, opaque, scatter light, and are commonly suspended in a medium or binder. The size of the pigment particles was larger than that of the dyes, possibly leading to a lower particle packing ratio and a higher transmission rate, even though the particles scattered UV light. Therefore, smaller constituent particles exhibit a higher packing ratio and a greater scattering contribution, rendering them more effective at blocking UV radiation.

Conclusions

Considering the degree of UV inhibition with blueprinting characteristics, this study confirms that plastics such as polyethylene and polyvinylidene chloride effectively block UV light. The structural differences between pigments and dyes lead to different UV inhibition rates. These data can be used to develop products that efficiently reduce the risk of UV radiation-induced diseases. The low UV inhibition of plastics used primarily in containers, such as polypropylene and polystyrene, and the high UV inhibition of PET, which is reused as shirts, opens up the possibility of producing products with high UV inhibition. Similar experiments would be conducted with nonplastic materials to address the issue of marine plastics and strike a balance between human health and environmental protection.

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