Experimenting with cameraless photography using turmeric and borax: An introduction to photophysics

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Experimenting with cameraless photography using turmeric and borax: an introduction to photophysics

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Abstract

An alcoholic extract of the spice turmeric can be used to create a light-sensitive dye that can be used to stain paper. On exposure to sunlight, the dyed paper can be used to capture photographic images of flat objects or reproduce existing images through the preferential degradation of the dye in light-exposed areas over a time period of a few hours. The images can be developed and preserved by spraying the exposed paper with a dilute solution of borax which forms coloured organo-boron complexes that limit further degradation of the dye and enhance the colour of the image. Similar photochemical reactions that lead to the degradation of the turmeric dye can also be used for reducing the organic pollution load in wastewater produced by many industrial processes and in dye-sensitized solar cells for producing electricity.

Introduction

Although we now live in a world where almost Q.1 all photographic images are captured digitally, this has not always been the case. For more than a century until comparatively recently, photographs were captured through chemical reactions on light-sensitive emulsions on glass plates or photographic film. Over this period, silver-based processes became dominant, but in the early part of the nineteenth century, researchers investigated a number of other chemical processes to capture photographic images.

One of the more obscure fields of investigation during the nineteenth century was the use of natural pigments from plants in photography. Although it had been known for many centuries that cloth stained with many dyes extracted from plants tended to fade in sunlight, the phenomenon was only seriously investigated in the early part of the nineteenth century. In 1816, Henri August Vogel in Paris found that coloured alcoholic extracts of various flowers faded after exposure to sunlight after a few days, but showed no change in colour if the solutions were exposed behind red glass. He found that paper and cotton fabric stained with the extracts showed the same pattern of fading. Further investigations based on these observations led to the development of the anthotype photographic process by Sir William Herschel in 1842 (Snelling 1849).

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Anthotypes are made by coating paper with water or alcohol extracts of plant pigments. The dried paper is then masked either with a flat object or a picture on a transparency and exposed to sunlight, usually beneath a sheet of clear glass. Over time periods of days to weeks, an image is gradually formed on the paper by the selective bleaching of areas exposed to sunlight. The process was seen as a method of producing or reproducing images of botanical specimens or other objects without the need for a camera or expensive or hazardous chemicals. However, the process was found to be impractical and was soon abandoned due to the long exposure times required, and because the resultant images were vulnerable to further fading.

Despite these limitations, anthotypes remain a useful and aesthetically pleasing way of recording photographic images of some objects. In particular, they are useful from an educational perspective because they can be produced without the need for expensive or hazardous chemicals, and without a camera or darkroom facilities. More importantly, producing these images is an interesting and fun way of introducing a range of sunlight-driven photochemical reactions which are being used in fields as diverse as wastewater treatment and in the production of energy through the use of dye-sensitized solar cells.

One potential drawback of using anthotypes as an educational tool is the long exposure time (days to several weeks) that is usually required to produce photographic images with natural dyes derived from plant material. However, this exposure time may be greatly reduced (to a period of a few hours) with careful dye selection, and if the exposed dyes are treated with suitable inorganic complexing agents to intensify the colour of resultant images and to limit their further degradation.

This is illustrated in this paper through the use of a turmeric dye which is treated with a dilute solution of borax to produce highly coloured organo-boron complexes in the resultant anthotype images.

Dye selection process for producing anthotypes

It is likely that the following criteria would need to be met for anthotypes to be a useful educational tool in a classroom environment.

(i) The natural dye should be extremely photosensitive and prone to rapid degradation on exposure to sunlight to enable images to be captured in a reasonable time frame.
(ii) It should be readily available for little or no cost.
(iii) It should be available in a form that does not require students to spend excessive time grinding and extracting the material from plant products.
(iv) It should have a low toxicity and be safe to use.

Historically, a very large number of dyes have been extracted from plant materials for staining cloth, and each of these dyes fades at a different rate in sunlight. Therefore, it would be extremely difficult to determine the best dye to use for capturing photographic images without undertaking extensive testing of the response of a wide range of natural dyes to sunlight.

Fortunately, much of this work has already been undertaken by scientists who are interested in preserving and displaying historical articles of clothing and other textiles in museums. These scientists have measured a property known as the 'lightfastness' of a wide range of natural dyes that have been used in the past to colour textiles (see e.g. Padfield and Landi 1966, Cox-Crews 1982). Natural dyes which have an extremely poor lightfastness and which are readily available are likely to be the most suitable dyes for producing anthotypes.

Work undertaken by textile conservators has shown that a bright yellow dye extracted by alcohol from the spice turmeric has an extremely poor lightfastness, making this material a good candidate for producing anthotype images. Additionally, this spice is now widely available at low cost in dry powdered form on supermarket shelves in many parts of the world, increasing its suitability for educational use. However, one significant drawback with the use of turmeric is the poor contrast between the bright yellow of Q.2 the dye and the white paper background, making it difficult to view anthotype images produced with turmeric. This problem can be overcome by treating the resultant image with a dilute solution of borax.

Extracts of turmeric contain a chemical compound known as curcumin which is known to react with borate solutions to form a number of

Table 1. Materials needed to produce turmeric and borax anthotype images.

Material	Use	Source(s)
Small photograph frame	Support for dyed paper	Variety store
Clothes pegs	Clamping the photograph frame	Supermarket
Powdered turmeric	Source of dye	Supermarket
Borax	Image developer	Supermarket/hardware store
Methylated spirits (denatured alcohol)	Extracting dye	Supermarket/hardware store
Small paint brush	Applying dye	Arts supply store/hardware store
Cartridge paper or watercolour paper	Paper source	Arts supply store
Spray bottle	Applying borax to images	Variety store/hardware store
Plastic teaspoons		
Small plastic containers		

organo-boron complexes, particularly the complexes known as rosocyanine and rubrocurcumin. Under acidic conditions, both rosocyanine and rubrocurcumin have an intense red colour which is used as a sensitive indicator of the presence of borates in solution. However, under the alkaline conditions present in borax solutions, a range of reddish-brown to purple-brown colours is produced which show a good contrast against a white background and can therefore be readily seen in anthotype images. These complexes are also more resistant to fading in strong light than untreated turmeric dye.

Producing anthotype images with turmeric and borax

The materials required to produce anthotype images are outlined in table 1. The turmeric dye is made by adding a teaspoon of powdered turmeric to a small plastic container (with a capacity of about 50 ml) and covering the powder with about 20 ml of methylated spirits (denatured alcohol).

The borax solution is made by adding about two teaspoons of powdered borax to about 100 ml of tap water. This solution is then placed in a plastic spray bottle.

The best anthotype images are produced with high-quality absorbent papers such as cartridge paper or paper from watercolour sketch pads, but other types of paper can be used if these are not available (images can even be produced on plain paper towelling). The paper should be cut into pieces that are of a similar size to the photograph frame that will be used as the support for producing the anthotype images.

The paper is dyed by applying an even coating of the turmeric dye solution with a small paint brush (avoid applying too much undissolved particulate matter to the paper). This should be carried out indoors avoiding exposure to bright lights to limit the degradation of the dye. The paper should be left to dry for about 10 min before it is placed on the hardboard back-support of a photograph frame and covered with a flat object (such as a leaf or pressed flower) for imaging. The clear glass cover of the photograph frame is then placed carefully on top of this assemblage and is clamped in place using three or more clothes pegs (figure 1).

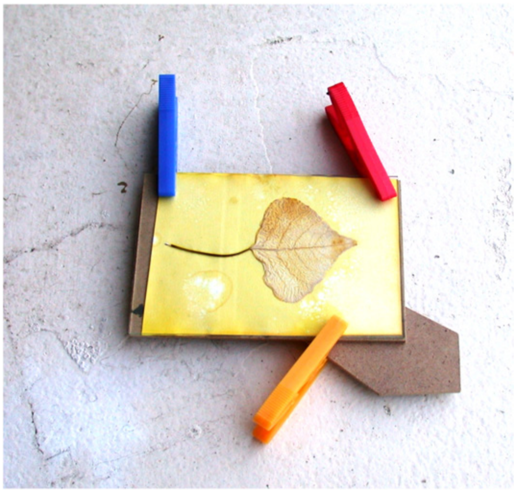

Figure 1. Creating an image of a leaf on turmeric-dyed paper in sunlight using a photograph frame.

The assembled photograph frame is then placed outside in full sun to enable the anthotype image to be exposed. The necessary exposure time will depend on weather conditions, seasonal factors and the site location, but typically exposure times of less than a day will generally be adequate. The images shown in figures 2 to 5 were produced at latitude 32 °S in the southern hemisphere

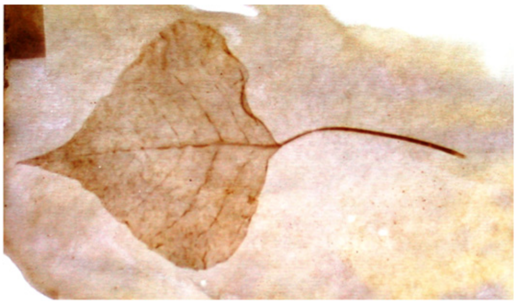

Figure 2. Turmeric and borax anthotype image of a leaf captured in a photograph frame by exposure to sunlight for a 3 h period.

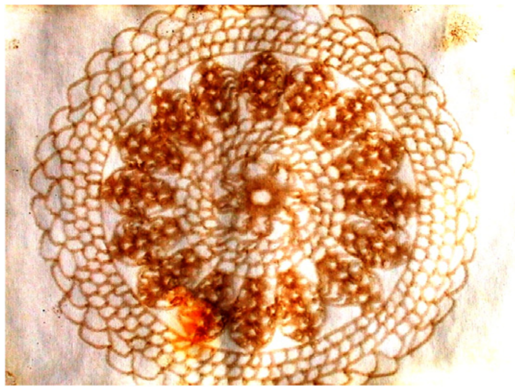

Figure 3. Turmeric and borax anthotype image of a crocheted doily captured in a photographic frame by exposure to sunlight for a 5 h period.

summer with exposure times of between 1 and 4 h, but longer exposure times may be necessary under cloudy conditions, at higher latitudes or at different times of the year. The best way of determining the time required to produce an image is to monitor the colour of dyed paper that is directly exposed to sunlight. A suitable image is generally produced when this colour fades from its initial bright yellow colour to a paler lemon-yellow tint.

After a suitable period of exposure to sunlight, the dyed paper is removed from the photograph frame and the exposed surface is sprayed with a fine mist of borax solution until its colour changes to a brownish-red colour. Over a time period of up to 10 min, an image will progressively appear on the paper. The paper should then be set aside to dry for a few hours.

Figures 2 and 3 show examples of anthotypes produced when flat objects are placed directly on the dyed paper for imaging. However, existing photographs can also be reproduced by this process. This was done by printing the image in black and white on standard A4 photocopier paper, trimming the paper to size and placing it face upwards on top of a piece of turmeric-dyed paper in a photograph frame. This was then exposed to bright sunlight and developed in the same manner as anthotype images produced from flat objects. An example of a reproduction of a photograph produced by this method is shown in figure 4.

Figure 4. Concrete pillars, bare branches and a winter sky at the Jewish Museum in Berlin. The image was captured by covering turmeric-dyed paper with a paper print-out of a black and white photographic image (face upwards) in a photograph frame. The exposure time in sunlight was 2 h.

Relevance for introducing the field of photophysics

The chemical response of turmeric dye to sunlight can be used to illustrate some aspects of photophysics, the study of the interaction of light with matter.

One fundamental principle underlying the interaction of light with matter is that chemical reactions can be initiated or sustained by energy

Figure 5. Anthotype image produced by masking the dyed paper with blue and orange cellophane to selectively filter out part of the visible spectrum. The exposure time in bright sunlight was 1 h. Q.A

provided by electromagnetic radiation (so-called 'photochemical' reactions). However, light must be absorbed by a chemical substance for a photochemical reaction to take place. This principle known as the Grotthus–Draper law was postulated in the early part of the nineteenth century, and indicates that only certain wavelengths of light are involved with initiating photochemical reactions with particular chemical substances.

This principle can be illustrated with turmeric-dyed paper by covering the paper with cellophane of various colours to block out various parts of the visible spectrum before exposure to sunlight. Figure 5 shows the effect of selectively masking a piece of turmeric-dyed paper with orange and blue cellophane before exposure to sunlight for 1 h. This figure shows that light that passes through glass and the blue cellophane (which blocks light with wavelengths at the red end of the visible spectrum) bleaches the turmeric dye to the same extent as light that passes through plain glass, suggesting that red light has a limited effect on the dye. This is supported by the image produced on turmeric-dyed paper that is covered by orange cellophane and glass which is significantly less exposed than dyed paper masked by either blue cellophane or plain glass. Clearly, the turmeric-dyed paper is not uniformly sensitive to exposure to light across the visible spectrum.

A second fundamental principle of photophysics is that the physical or chemical changes that occur in molecules that are absorbing light of a particular wavelength will be proportional to the number of photons absorbed by the molecule. This principle is known as the Stark–Einstein law and was postulated in the early part of the twentieth century. The amount of energy provided by the absorbed photons to a photosensitive chemical substance is given by:

$$\Delta E = h\nu = (hc)/\lambda$$

where h is Planck's constant; c is the speed of light; ν is the frequency of the light; and λ is the wavelength of the light.

This principle can be seen in action by the level of contrast exhibited by the anthotype images shown in figures 2–4, particularly in figure 2 where the degree of bleaching of the turmeric dye appears to have been directly proportional to the amount of light that passed through a leaf onto the underlying paper. This has enabled a clear image to be formed, reproducing features such as veins within the overlying leaf.

The energy absorbed by a photosensitive molecule from visible light (of the order of 2 to 3 eV) typically changes the configuration of electrons within the molecule, producing a highly energetic state. This energy can subsequently be dissipated by the emission of less-energetic electromagnetic radiation (fluorescence), by the transfer of electrons within or between molecules, or by the forming or breaking of chemical bonds. In the case of constituent photosensitive chemical substances in the turmeric dye, energy absorbed from visible photons produces highly energetic forms of oxygen which rapidly react with organic matter and progressively bleach constituents of the dye. Similar photochemical bleaching reactions, often in the presence of metal oxide semiconductors like titanium dioxide, are often used to reduce the content of organic pollutants in wastewater from a variety of industrial processes. The energy captured by the irradiation of photosensitive dye molecules can also be used to produce an electric current in dye-sensitized solar cells. These devices have the potential to become a cheap source of solar power, and are described in some depth in Smestadt (1998) and Grätzel (2001).

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