Fluorescence and the Color of Day Glo Paints

To the casual observer, a white piece of paper seems white whether viewed at dawn, noon, or dusk. In contrast, fine arts painters must compare the colors of their paint mixtures to the scene they are viewing. They recognize that the actual color of an object depends as much on the color of the light used for illumination as it does on the nature of the object. The effect is most obvious with objects that appear white or yellow in sunlight and some of the new "Day Glo" colors (especially the "Saturn" and "Arc" yellows[1]).

Neglecting perceptual factors and fluorescence effects, the color of whites and yellows change with illumination spectra because they are comprised of the broadest band spectrum.[2] White contains light from 400-700 nm; yellow is almost as broad, with components from 500-700 nm. Consequently, yellow paint looks red when illuminated with pure red light, green when illuminated with pure green light, and nearly black when illuminated with pure violet light.

It's fun to see the change in appearance of a pigment with illumination by painting under different colored lights. This works especially well when using Day-Glo paints under white, red, green, or blue lights (see Fig. 1, page 88). Secret pictures or messages can be hidden in a painted scene (to be revealed only under the right lighting) or the mood of a picture can be made to change with illumination. A good source of different colored lights can be had by placing colored acrylic sheets (available from art supply stores) on an overhead projector; "party bulbs" (commercially available incandescent bulbs with a colored envelope) don't work as well.

The above notwithstanding, Day-Glo pigments look *brighter* than white paint does in daylight. Clearly, these pigments are doing more than reflecting portions of the incident spectrum.

Day-Glo colors contain fluorescent long-chain organic dyes diluted in resin solvent.[3] Fluorescence occurs by the absorption of a photon (often from the UV or blue end of the visible spectrum) and excitation of an electron into one of the many higher energy vibrational states. Some energy is dissipated by reconfiguring bonds, and shortly afterwards (10^{-13}-10^{-11} sec.) the excited electron relaxes into a singlet state. Fluorescence occurs as the electron drops from the singlet state to a vibrational energy level near the ground state (within 10^{-9} sec.), so the color of the emitted light is virtually independent of that of the absorbed light. The incident light need only be of short enough wavelength to excite the dye molecule (but not too short as to decompose the dye). If the excited state electron decays into a triplet state instead of a singlet state, the emission takes much longer ($>10^{-4}$ s) and is called phosfluorescence. (Glow-in-the-dark paints are phosfluorescent; Day-Glo pigments are fluorescent.)

Alberta Yellow (a yellow-green coumarin dye used in some Day-Glo pigments) has a nonfluorescent reflectance of approximately 80%.[3] With fluorescence, the dye emits 77% more light between 500-550 nm than perfect white (100% reflectance). The dye is said to have a peak radiance factor of 177%. Dyes can be used in combination as sensitizers to various regions of the incident spectrum. Rhodamine F5G alone absorbs in the green and emits in the red end of the visible spectrum. Alberta Yellow absorbs in the blue and can be used as an additive to boost the amount of available green light to the F5G, resulting in a higher peak radiance factor than of F5G exposed to sunlight alone. The peak radiance factors of some dye combinations exceed 300%.[3]

Fluorescent dyes are also used in white cloth and paper. Manufacturers of fabrics and detergents include proprietary "optical brighteners" to make white fabrics appear self-luminous under normal lighting. Fluorescent dyes are also included in white paper for the purpose of adding some blue fluorescence to compensate for their otherwise natural yellowish tinge.[4]

Many experiments on fluorescence can be done with household objects if a UV lamp is also available. However, it is important to determine whether the UV source emits predominantly UVA (320-400 nm), UVB (290-320 nm) or UVC (200-290 nm) light. "Black lights" and sunlamps emit predominantly UVA. There do not appear to be federal exposure limits to this wavelength range,[5] but UVA will redden the skin with sufficient dosage.[6] Titanium-containing pastes and "UF-3" plastic can be used to block it. Both UVB and UVC are termed "short UV." Short UV can be obtained from lamps that are used to cure epoxies and optically-activated cements; prolonged exposure is known to be harmful to both skin and eyes. Short UV is blocked by over-the-counter sunscreens containing PABA and *some* (but not all) glasses.

In an otherwise dark room, Day Glo pigments illuminated by long UV light appear self-luminous; white cloth, paper, and lint will glow violet. Some plastics (*e.g.*, the clear plastic on the Fisher Price "Flutter Ball" baby toy) glow an eerie green, some (*e.g.*, red theatre gel) glow orange, while still other objects look dark.

There are compounds that don't fluoresce under long UV, but will emit visible light under a short UV source. Certain naturally occurring minerals, *e.g.*, Zn_2SiO_4 (Willemite) with some of the Zn replaced by manganese, look drab under normal lighting conditions, but glow bright greens, reds, and blues under short UV (compare Figs. 3 and 4, page 88).[7] The phosphors in a fluorescent lighting tube can be made to glow without switching on the lamp by holding a short UV source close to the tube.[8] On the other hand, the fluorescence of Day-Glo pigments, etc., can be suppressed if illuminated with short UV through a slab of glass. With this in mind, it may help to limit the experimenter's exposure to the short UV

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by viewing everything through a glass plate (*e.g.*, set the fluorescent materials and source inside a glass aquarium and view only through the glass). PABA sunscreen is also recommended.

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Note: The figures accompanying this article appear on page 88.

REFERENCES

1. Day Glo is a trademark name for a patented collection of fluorescent pigments, available in tempera and acrylic paints and manufactured in the U.S. by Day-Glo Color Corp., Lawter Chemical Corp., Sargent Art, and Radiant Color Division of CIBA-GEIGY. Paint chips and reflectance spectra of Day-Glo pigments are given in Day-Glo Technical Bulletin #2003, available from Day-Glo Color Corp., 4515 St. Clair Ave., Cleveland, Ohio 44103.
2. This explanation assumes that the object is viewed in isolation of other colors (*i.e.*, the object is surrounded by black). Color interactions, inhibition effects, and the visual response curve are omitted from this argument.
3. R.A. Ward and E.L. Kimmel, "Luminescent materials (fluorescent daylight)" from the *Encyclopedia of Chemical Technology* 14, 3rd ed., Wiley, 1981.
4. S.J. Williamson and H.Z. Cummins, *Light and Color in Nature and Art*, Wiley, 1983, 159.
5. Title 21 Code of Federal Regulations on sunlamp products and UV sources (sec. 1040.20) and high-density mercury arc lamps (sec. 1040.30).
6. R.W. Gange *et al.*, "Action spectra for cutaneous responses to ultraviolet radiation," from *Biological Effects of UVA Radiation*, F. Urbach and R.W. Gange, eds., Praeger, 1986.
7. C.S. Hurlbut Jr., *Minerals and Man*, Random House, 1970, Chap. 12.
8. Fluorescent lights are typically configured as glass tubes filled with argon and mercury vapor and containing tungsten filament electrodes at either end. The inner wall is coated with phosphor, *e.g.*, calcium halophosphate (zinc beryllium silicate, which once made broken fluorescent tubes a health hazard, is no longer used). An electric discharge produces an intense UV light, which is absorbed by the phosphor and re-emitted in the visible spectrum.
9. Douglas Goodman, "Optics Experiments with an Overhead Projector," Rochester Local Section Optical Society of America talk, Oct. 22 1991.