

Understanding Paper Whiteness

Paper whiteness quantifies a paper's ability to equally reflect a balance of all wavelengths of light across the visible spectrum. Paper brightness measures the amount of light reflected from the surface of paper at one specific wavelength (457 nm) in the blue region of the spectrum, whereas whiteness measures the relative balance of light reflected across the full visible spectral range (approximately 380nm – 720nm).



An object (e.g., paper) appears to be white if it reflects light equally at all wavelengths across the visible spectrum. If some wavelengths are absorbed while others are reflected, the object exhibits the color of the reflected light—color that can be measured. Pure white, therefore, is an achromatic reflector of perfectly balanced light.

Unlike paper brightness which only quantifies a specific wavelength of reflected blue light, paper whiteness formulas are designed to closely parallel the experience of normal human vision.

Multiple standards and measurement methodologies exist for determining the whiteness of paper.¹ The most common whiteness measurement standard used worldwide is ISO 11475:2004, also known as CIE whiteness. ISO 11475:2004 specifies a whiteness index and measurement methodology which utilizes diffuse illumination with a light source configured to CIE standard illuminant D65.

¹ Whiteness measurement standards include TAPPI T 560 (d/0° geometry, illuminant C/2°); TAPPI T 562 (45°/0° geometry, illuminant C/2°); ISO 11476 (d/0° geometry, illuminant C/2° observer); ISO 11475 (d/0° geometry, CIE standard illuminant D65/10° observer).

The CIE standard illuminant D65 contains considerable UV energy. CIE D65 is an outdoor daylight illuminant, with a defined spectral power distribution approximating average mid-day sunlight.²

CIE whiteness is a single number value expressed as whiteness units (0-100). A non-fluorescing white paper which reflects all wavelengths of light in perfect balance will theoretically produce a CIE whiteness measurement of 100.³

Due to visual preference, CIE whiteness equations are formulated with a slight bias toward the short wavelength (blue) area of the visible spectrum. Therefore, a high CIE whiteness value will represent a paper that appears slightly blue and very slightly violet.

It is not uncommon to encounter CIE whiteness values well above 100 due to the fluorescent components of high-quality papers.

In response to the design community and the graphic arts industry's demand for brighter "blue white" papers, fine paper manufacturers commonly add chemical compounds called optical brightening agents or fluorescent whitening agents (OBAs/FWAs) to commercial printing papers. These chemicals have the unique ability to absorb ultraviolet radiation and then transform and re-emit invisible UV wavelengths as high energy photons of light in the violet/blue area of the visible spectrum—a phenomenon called *fluorescence*. Invisible UV wavelengths such as contained in sunlight, ISO 3664:2009 standard lighting, and, to varying degrees in many other artificial light sources, are therefore absorbed by optical brightening agents in fine printing papers and transformed into wavelengths of energy perceptible to human viewing. This transformed UV energy becomes "visible" blue light radiating from the paper's surface which supplements light projected by the illuminant and drives the CIE whiteness value well over 100. Therefore, papers with high whiteness values typically appear bluer.

The fluorescence component of a CIE whiteness measurement can be separately quantified and expressed. To isolate the contribution of fluorescence to the CIE whiteness data, separate measurements are made with and without the use of a UV-cut filter. A fluorescence value is then calculated from the mathematical difference between the UV included and UV excluded measurements. Although the appearance of a high whiteness paper is more highly influenced by the UV components of various illuminants, high whiteness papers typically improve the dynamic range of print and produce brighter printed images.

² CIE illuminants are defined by the International Commission on Illumination—also known as the CIE from its French name, the Commission Internationale de l'Éclairage.

³ A companion index/measurement system is the CIE tint index which quantifies the non-whiteness of paper—i.e., the deviation from perfect white toward the red or green spectral regions. The further a tint value is from zero (positive or negative), the greater the tint of the paper. Therefore, a perfectly white paper has a whiteness value of 100 and a tint value of 0.