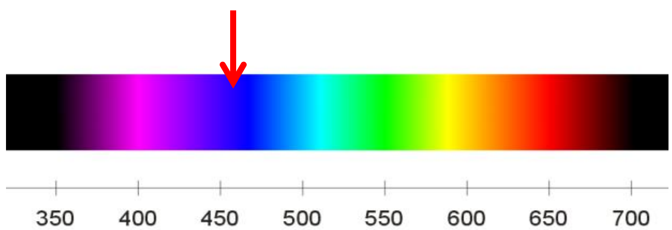
Understanding Paper Brightness

Introduction

Brightness quantifies the percentage of blue light reflected from the surface of paper as measured at a specific effective wavelength of 457 nanometers (with a half-peak bandwidth of 44 nm).[1]



Brightness does not indicate the color or relative shade of the paper since a single number reflective value measured at 457 nm ignores all other wavelengths of light reflected across the visible spectrum. A brighter paper, therefore, reflects a greater amount of blue light than does the surface of a less bright paper.

Three different brightness measurement methodologies are used worldwide. Each of these methods will produce a different brightness number when used to measure the same paper sample. It is, therefore, important to understand basic concepts of each of the three testing methods, including photometric principles, characteristics of the illuminants, and illumination/observer—reflected light measurement geometries.

Due to differences in illuminants and illumination/reflected light measurement geometries, there are no direct correlations between brightness measurements produced by the three methods.

[1] Monitoring the photometric curve response throughout the pulp bleaching cycle shows that changes are greatest in the short wavelength area (the violet/blue region of the visible spectrum). Therefore, 457 nanometers has been determined to be an appropriate wavelength for optimal measurement of light reflection to monitor pulp and paper brightness.

The three paper brightness standards are briefly described as follows.

TAPPI (T 452) / GE Brightness

The Technical Association of the Pulp and Paper Industry (TAPPI) has authorized method T 452 for use in determining the brightness of paper. TAPPI T 452 brightness is often referred to as GE brightness since General Electric invented one of the first paper brightness testing machines which became the industry standard for decades. The GE brightness measurement scale has been in place since the 1930s. Considering there are two TAPPI standards for brightness, we will hereafter refer to the T 452 method as GE brightness.

GE brightness is used for specification of paper brightness primarily in North America.

The International Commission on Illumination—also known as the CIE from its French name, the Commission Internationale de l´Eclairage, has defined the spectral power distributions of several illuminants which are divided into three categories: tungsten, daylight, and fluorescent.

When measuring GE brightness, the paper sample is illuminated with a CIE illuminant C defined light source;[2] a simulated daylight illuminant containing a certain amount of U.V. energy.[3] In-line "brightness" filters are also applied which modify the spectral characteristics of the reflected illuminant.

TAPPI T 452 specifies directional illumination/measurement geometry of 45° illumination, 0° observation (i.e., 45°/0°). In other words, the test instrument emits light which strikes the surface of the paper at a 45° angle of incidence. A photocell receptor is positioned at the N or 0° position, perpendicular to the paper sample. The directional illumination/reflected light measurement geometry is illustrated in figure 1.

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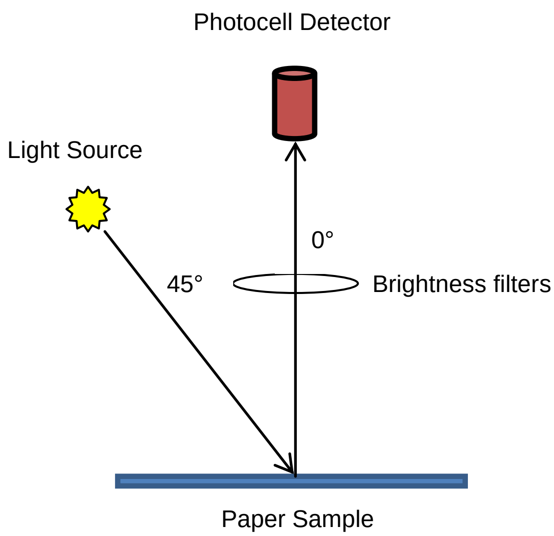
[2] CIE illuminant C is no longer a CIE *standard* illuminant. However, the International Commission on Illumination publishes a spectral power distribution, tristimulus values, and chromaticity coordinates for illuminant C. Illuminant C is used by many spectral and colorimetric measurement systems.

[3] ISO 2470-2 states that the UV content of CIE illuminant C approximates levels of UV energy present in certain indoor viewing conditions—significantly less than the UV content of CIE standard illuminant D65.



Directional Geometry (45/0°)

Figure 1

A focused beam of light strikes the paper sample at 45° and, after passing through a series of filters, the reflected light is received by the photocell.

The quantity of reflected light received by the photocell is measured and expressed based on a scale relative to the amount of light that would be reflected from a 100% reflective magnesium oxide standard. Therefore, the expressed brightness measurement mandated by the GE methodology is not an exact percentage of light actually reflected from the paper.

There are advantages and disadvantages to the directional geometry method specified by the TAPPI T 452/GE brightness standard.[4] One of the challenges of directional illumination and measurement is that the focused illumination geometry makes the system sensitive to non-uniformities in the paper. Different test results may be obtained when measuring in the machine and cross-machine directions (i.e., parallel to paper grain and across paper grain direction respectively). The industry typically measures the directional brightness of paper samples with orientation parallel to grain direction.

[4] Technidyne Corporation *Technical Bulletin No: 101: Diffuse vs. Directional Brightness Measurement,* provides an excellent overview of the advantages and disadvantages associated with the directional and diffuse measurement systems.

ISO Brightness (ISO 2470-1)

The ISO paper brightness measurement system, as defined by ISO 2470-1 and TAPPI T 525, is used for specification of paper brightness throughout Europe and in many other parts of the world.

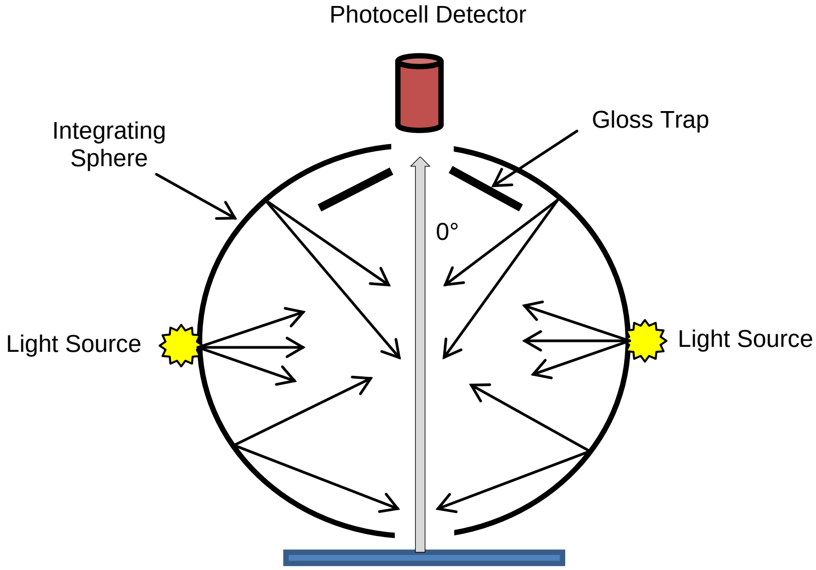
When measuring ISO brightness, the paper sample is illuminated with a CIE illuminant C light source; a daylight illuminant containing a certain amount of U.V. energy. This is the same illuminant used by the TAPPI T452/GE paper brightness measurement system (see footnotes 2 and 3).

ISO 2470-1 specifies an illumination/reflected light measurement system which utilizes diffuse optical geometry (diffuse illumination, 0° observation; i.e., d/0°). The instrument used to measure ISO brightness illuminates the samples with light projected by two lamps into an integrating sphere. The interior wall of the sphere is coated with a highly reflective non-glossy material which allows the light to inter-reflect and illuminates the paper sample from all directions; i.e., diffusely. Photocells or diode receptors are positioned at the 0° position, perpendicular to the plane of the paper sample, and record the amount of light reflected from the paper's surface. The computer analyzes the spectral power distribution of the reflected light and quantifies the energy response at 457 nanometers. Figure 2 illustrates the diffuse illumination/observation system.

Diffuse measurement geometry integrates the light reflected across non-uniformities of the sample and averages the effects of reflective differences due to paper directionality. Therefore, ISO brightness measurements are less sensitive to paper surface and directional orientation irregularities.

Unlike the TAPPI T 452/GE method, the ISO brightness measurement system quantifies the actual percentage of light reflected from the sample at 457 nm rather than relating measurements to a scale correlated to the percentage of light reflected by an external standard.

The ISO brightness methodology typically produces a higher brightness number than the TAPPI T 452/GE method when measuring the same paper sample due to slightly greater fluorescence stimulation, the illumination/light measurement geometry, and the brightness scales used.



Diffuse Geometry (d/0°)

Figure 2

D65 Brightness (ISO 2470-2)

The D65 brightness measurement system (ISO 2470-2) is essentially the same as the previously described ISO system (ISO 2470-1) with the exception of the specified illuminant.

D65 brightness uses the CIE standard illuminant D65, an outdoor (average north sky) daylight illuminant containing a significantly greater amount of UV energy than CIE illuminant C (as specified for ISO brightness measurement). Therefore, the additional UV energy emitted by the D65 standard illuminant will produce a greater fluorescence response when the paper contains optical brightening agents. Consequently, D65 brightness measurements will be significantly higher (when paper contains optical brightening agents) than those produced by the TAPPI T 452/GE or the ISO brightness methods which specify an illuminant with less UV content.

The following provides a comparison of key elements for each brightness measurement standard:

Standard	Illumination/Viewing Geometry	Illuminant
TAPPI T 452 / GE Brightness	Directional (45°/0°)	CIE illuminant C (filtered response)
ISO Brightness (ISO 2470-1)	Diffuse (d/0°)	CIE illuminant C
D65 Brightness (ISO 2470-2)	Diffuse (d/0°)	CIE standard illuminant D65

If a paper contains optical brightening agents, the GE brightness methodology will produce the lowest brightness number while D65 brightness will produce the highest.

Note regarding fluorescence and brightness measurements in excess of 100%

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 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" light radiating from the paper's surface.

When illuminated by a light source containing a significant amount of U.V. energy, the energy transference process (from invisible to visible wavelengths) is activated and an optical brightener enhanced paper may actually reflect more *total light* than it receives from the light source (i.e., visible light reflected from the light source plus re-emitted "blue" light transferred from the invisible realm of the electromagnetic spectrum).

Since paper brightness is measured in the blue area of the visible spectrum (457 nm), the very region where the process of fluorescence redirects UV energy to become visible light, illuminants with high UV energy content (e.g., D65) can produce brightness measurements in excess of 100%.

Fluorescence may be quantified with both directional and diffuse measurement systems. 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. Note that the measurement system must utilize a controlled, spectrally defined illuminant since the spectral power distribution characteristics and UV energy content of the light source will significantly affect the balance of reflected light and the degree of fluorescence.

Comparative brightness measurements

As previously pointed out, each of these brightness measurement methods will produce a different brightness number when used to measure the same paper sample.

Due to slight modification of the illuminant, measurement geometries, and the GE standard brightness scale, TAPPI T 452/GE brightness will yield the lowest brightness number of the three methods. TAPPI T 452/GE brightness numbers will rarely exceed 100. When measuring the same paper sample, ISO brightness numbers will be slightly higher than those produced by the GE brightness method. The D65 brightness measurement methodology will return the highest readings—often in excess of 100% for papers containing fluorescent components. This is due to the high UV energy content of the CIE standard illuminant D65.

The three methods may produce similar brightness numbers when measuring a common paper with low fluorescence. However, as fluorescence increases, the measurements produced by the three different methods will become progressively dissimilar.

References

TAPPI T 452 om-08; Brightness of pulp, paper, and paperboard.

ISO 2470-1, Second edition 2016-09-15; Paper, board and pulps—Measurement of diffuse blue reflectance factor; Part 1: Indoor daylight conditions (ISO brightness).

ISO 2470-2, First edition 2008-11-01; Paper, board and pulps—Measurement of diffuse blue reflectance factor; Part 2: Outdoor daylight conditions (D65 brightness).