2. Significance

2.1 The color appearance of paper and paperboard is important for its aesthetic value in marketing packaged products, as an aid to distribution of multi-ply forms, to differentiate pages or sections of published literature, in art work, and in many other applications.

2.2 A numerical definition of color is essential to good quality control and to customer-producer relationships.

3. Definitions

3.1 *Dominant wavelength (of an illuminated object)*, the wavelength of spectrally pure energy which when mixed with the illuminant in suitable proportions will match the color of the specimen.

3.2 *Purity*, *excitation,* the ratio of the distance on a CIE chromaticity diagram between the achromatic point and the specimen point to the distance along a straight line from the achromatic point through the specimen point to the illuminant spectrum locus. The term "saturation" is also applied to this quantity.

3.3 *Luminosity*, the scale of perception representing a color's similarity to achromatic colors between black and white. This quantity is also known as "luminance" and "luminous reflectance."

3.4 *L*, *a*, *b*, *L**, *a**, *b**, these symbols are used to designate color values as follows: *L*, *L** represents lightness increasing from zero for black to 100 for perfect white; a, *a** represents redness when positive, greeness when negative; and *b*, *b** represents yellowness when positive, blueness when negative. When *a** and *b** are simultaneously zero, they represent grey.

3.5 *L**, *C**, *h*, *L** is as described in 3.4, *C** represents chroma, and *h* represents hue angle.

3.6 ΔE, ΔE^*, ΔE (CMC), the overall color difference values take into account lightness/darkness differences as well as chromatic differences. The intent is for a given value of ΔE, ΔE^*, ΔE (CMC), to represent the same visual perception of color difference anywhere in color space.

4. Apparatus

4.1 *Instrumental components*[1]*,* consisting of a means for fixing the location of the surface of the specimen, a system for proper illumination of the specimen, suitable filters, gratings, or other optical components for altering the spectral character of the rays reflected from the specimen, photosensitive receptors to receive the reflected rays, and a means for transforming the receptor outputs to tristimulus functions.

4.2 *Spectral characteristics*

4.2.1 *Incident light.* The spectral power distribution of the light incident on the specimen determines the extent to which reflected light may be augmented by fluorescence. The product of the spectral power distribution of the source and spectral transmittance of the glass lenses and infrared absorbing filter in the incident system should correspond to the energy distribution given as a function of wavelength in Table 1. This relative spectral power distribution may be approximated by a select combination of a tungsten filament source, a heat absorbing filter, and UV trimming filter in the incident beam. If the paper or paperboard being measured by a spectrophotometer contains no fluorophores (fluorescent components, i.e., optical brightness), the spectral distribution of incident light will not affect the measurement of color, provided that sufficient energy is available at each wavelength of measurement.

4.2.2 *Light energy.* The light energy incident on the test specimen should not appreciably heat or fade the specimen during the measurement. An infrared absorbing filter (heat filter) in the incident beam will normally prevent overheating the specimen.

4.2.3 *Spectral response.* The overall spectral response of the instrument, as determined by the combination of the spectral distribution of incident light on the specimen, the absorption characteristics of the filters and other light altering optics, and the photosensitive response of the receptors to light reflected from the specimen, shall simulate the CIE color-matching functions weighted by the relative spectral energy distribution of CIE Illuminant *C*/2° given in Table 2. All color spectrophotometer conforming to this method, T 524, must use the integration tables contained in ASTM E308, "Standard Practice for Computing the Color of Object by Using the CIE System," for the computation of tristimulus values *X, Y,* and *Z.*

[1] Names of suppliers of testing equipment and materials for this method may be found on the Test Equipment Suppliers list in the bound set of TAPPI Test Methods, or may be available from the TAPPI Quality and Standards Department.

Table 1. Relative spectral energy distribution incident on the specimen

Wavelength, nm	*Relative energy, E*
320	0.1
340	2.4
360	7.9
380	14.3
400	22.0
420	30.9
440	43.6
460	58.9
480	78.3
500	100.0
520	121.8
540	144.7
560	169.7
580	188.4
600	200.8
620	204.6
640	199.8
660	187.3
680	169.2
700	144.4

Table 2. Tristimulus functions for CIE Illuminant *C*/2°

Wavelength, nm	$E_c\bar{x}$	$E_c\bar{y}$	$E_c\bar{z}$
360	-0.001	-0.000	-0.006
380	-0.011	-0.000	-0.054
400	0.089	-0.001	0.393
420	2.919	0.085	14.033
440	7.649	0.511	38.518
460	6.641	1.382	38.120
480	2.364	3.206	19.564
500	0.069	6.910	5.752
520	1.198	12.876	1.442
540	5.591	18.258	0.357
560	11.750	19.588	0.073
580	16.794	15.991	0.026
600	17.896	10.696	0.013
620	14.018	6.261	0.003
640	7.457	2.902	0.000
660	2.746	1.008	0.000
680	0.712	0.257	0.000
700	0.153	0.055	0.000
720	0.034	0.012	0.000
740	0.007	0.003	0.000
760	0.002	0.001	0.000
780	0.000	0.000	0.000
SUM	98.073	100.000	118.232

4.3 *Geometric characteristics.* The angle of viewing is required to be separated from the angle of illumination in such a manner that only rays reflected diffusely from the test specimen enter the receptor, thereby excluding specular reflectance from the reading. The illuminating beam shall be centered about an axis of 45 ± 0.5° from the normal to the specimen surface. The direction of viewing shall be perpendicular ± 0.5° to the specimen surface. The angle between the axis and any ray of either the illuminating or viewing beam shall not exceed 22.5°.

NOTE 2: Interchange of incident and viewing directions is allowed under this method.

4.4 *Photometric characteristics.* The photometric system must be linear over the entire scale to within 0.2% of full scale. Photometric linearity may be determined by following the procedure described in TAPPI TIP 0804-06 "Photometric Linearity of Optical Properties Instruments." The instrument must be sufficiently stable that the reflectance factor reading will not fluctuate by more than 0.1% of full-scale deflection while the measurement is being made.

5. Standards

5.1 *Primary reflectance standard*[1]. The primary reflectance standard (100%) is an ideal uniform diffuser with a perfectly reflecting and diffusing surface (the perfect reflecting diffuser).

5.2 *Calibration standards*[1]. Calibration standards of ceramic and other materials, used to adjust and check the instrument scale, are available from instrument manufacturers and other sources. Reflectance values assigned to calibration standards shall be traceable to an instrument calibrated in terms of the primary standard and having geometric and spectral characteristics consistent with this method.

5.3 *Specific calibration standards*[1]. Specific calibration standards, colored similar to the paper to be tested, may be used to minimize the effect of spectral and geometric differences between instruments whose results are being intercompared. The "specific calibration" values for these ceramic standards should be established by first exchanging paper samples of the type of paper to be compared. The paper sample and the ceramic standard must not form a metameric pair.

5.4 *Black standard* – a black cavity with a reflectance factor which does not differ from its nominal value by more than 0.2 reflectance units at all wavelengths.

6. Calibration

6.1 The calibration of photometric scales shall be carefully checked at reasonable time intervals (at least monthly) in a manner to insure linearity and accuracy over all ranges. Calibration may be accomplished by placing a series of neutral filters of known transmittance in the incident beam, or by measuring the reflectance factor of calibrated opaque specimens.

NOTE 3: Reference (*1*) describes procedures for use of a set of special test panels in calibration of major photometric, spectral, and geometric characteristics of the instrument.

6.2 Photometric linearity and proper spectral response of the instrument are key factors for determining accurate color measurements. Colored standards should be carefully measured and their results intercompared to assure color measurement accuracy of the apparatus.

NOTE 4: Ceramic or glass standards may be cleaned, if necessary, using the procedures provided by the supplier of the standards.

6.3 Place the black standard against the specimen aperture and adjust the zero setting of the instrument.

6.4 Replace the black standard with a white calibration standard and set the instrument to the calibrated reflectance value of the standard at each filter position or wavelength, as appropriate.

7. Test specimen

From each test unit of the paper obtained in accordance with TAPPI T 400 "Sampling and Accepting a Single Lot of Paper, Paperboard, Containerboard, or Related Product," cut the sample to be tested into pieces large enough to extend at least 0.25 in. (6.35 mm) beyond all edges of the instrument aperture. Assemble the pieces into a pad which is thick enough so that doubling the pad thickness does not change the test readings. (With creped or other bulky papers care must be taken to avoid pillowing of the pad into the instrument by too much pressure.) Do not touch the test areas of the specimens with the fingers, and protect them from contamination, excessive heat, or intense light.