



The information and data contained in this document were prepared by a technical committee of the Association. The committee and the Association assume no liability or responsibility in connection with the use of such information or data, including but not limited to any liability under patent, copyright, or trade secret laws. The user is responsible for determining that this document is the most recent edition published.

CAUTION:

This Test Method may include safety precautions which are believed to be appropriate at the time of publication of the method. The intent of these is to alert the user of the method to safety issues related to such use. The user is responsible for determining that the safety precautions are complete and are appropriate to their use of the method, and for ensuring that suitable safety practices have not changed since publication of the method. This method may require the use, disposal, or both, of chemicals which may present serious health hazards to humans. Procedures for the handling of such substances are set forth on Material Safety Data Sheets which must be developed by all manufacturers and importers of potentially hazardous chemicals and maintained by all distributors of potentially hazardous chemicals. Prior to the use of this method, the user must determine whether any of the chemicals to be used or disposed of are potentially hazardous and, if so, must follow strictly the procedures specified by both the manufacturer, as well as local, state, and federal authorities for safe use and disposal of these chemicals.

Interrelation of reflectance, R_0 ; reflectivity, R_∞ ; TAPPI opacity, $C_{0.89}$; scattering, s ; and absorption, k

1. Scope

The following interrelationships will be found particularly useful in predicting the effect upon opacity when a change occurs in either the basis weight or the reflectivity of a sheet of paper. These interrelationships can also be used to evaluate relative contributions of different pulps, fillers and pigments to optical properties. Extensions of these procedures that are cited in the references can be used to evaluate multilayer structures such as coated paper or coated board.

2. Significance

The Kubelka and Munk (1) theory of light scattering was first published in 1931. The mathematical relationships between the optical properties of paper and the sheet thickness—based on derivations of the Kubelka and Munk equations concerning the reflection of light from diffusing media were first shown by Steele (2) with a series of charts relating the various measurable properties. In a detailed study, Judd (3) later investigated the Kubelka and Munk theory as applied to paper to discover the magnitude of departures from theory, and concluded that “except for deviations of less than one percent, the Kubelka and Munk theory applies to paper; the two constants of the theory, reflectivity, R_∞ , and coefficient of scatter, S , yield a useful description of the material of which paper is made.”

3. Kubelka/Munk relationships

3.1 Judd prepared a number of graphical aids, including the reflectance-opacity charts in this Standard Practice relating the important optical properties of paper. Properties as defined by Robinson (4) are:

R	=	reflectance of a layer (sheet, coating, ply) which has behind it a surface with a reflectance of R_g
R_g	=	reflectance of the background behind the layer whose reflectance is being considered
R_0	=	reflectance of the layer with ideal black background, $R_g = 0$
R_∞	=	reflectivity = reflectance of a layer so thick that further increase in thickness does not change the reflectance - TAPPI Brightness when the reflectance is measured through the standard blue filter
$R_{0.89}$	=	reflectance of the layer which has behind it a surface with reflectance of 0.89, i.e., $R_g = 0.89$

Approved by the Standard Specific Interest Group for this Test Method



Documents

Document Sharing Hub

$C_{0.89}$	=	$R_0 / R_{0.89}$ = TAPPI Opacity, as a fraction, when reflectances are measured through the standard green filter
sW	=	scattering power, a function of composition and grammage which characterizes the ability of the paper to redirect light (formerly used as sx).
kW	=	absorption power, which characterizes the ability of the paper to absorb light (formerly used as KX).
W	=	grammage
X	=	thickness
S	=	sW/W = light scattering coefficient
K	=	kW/W = light absorption coefficient

3.2 Note that opacity and scattering are normally characterized using the standard green filter. Therefore, the R_∞ value in the following equations is the R_∞ using green light, not TAPPI Brightness which is measured using blue light.

3.3 R_0 , R_∞ , $C_{0.89}$, and SX are interrelated so that when the numerical values of any two of these properties are known, the other values may be calculated or read directly from the charts. With two optical measurements on a sample of known thickness, it is possible by calculation or reading of the chart to determine the opacity of any sheet of the same fiber and filler composition but of different thickness. Another application for which an example is given allows determination of changes in opacity when absorption is changed by addition or removal of dye.

3.4 It was at once recognized that thickness, X , was an awkward variable with which to work from a practical standpoint. Workers in the field immediately began to divide SX by W , the grammage, to obtain the “scattering coefficient” with “grammage substituted for X .” One of the reasons given for this practice was the fact that grammage was usually more accurately known than was thickness. Van den Akker (5) pointed out that this substitution is perfectly justified and, in fact, allows additional benefits not immediately recognizable to the casual user of the Kubelka and Munk theory. In view of this, TAPPI has now adopted the term sW as the preferred nomenclature for scattering power—rather than the original SX . For additional information on terminology for optical measurements, see TAPPI T 1213 “Optical Measurements Terminology (Related to Appearance Evaluation of Paper).”

3.5 When one considers a mixture of two or more components in film or sheet, the specific scattering coefficient, s , of each of the constituents may be calculated on the basis of their relative grammages. Thus, the contribution of an individual component of a film or sheet is the product of its specific scattering coefficient and the grammage of the component in the reference unit of area (one ream, for example). This relationship is expressed as:

$$sW = s_1W_1 + s_2W_2 + \dots + s_nW_n$$

where W_1 , W_2 , and W_n are the grammages of the individual components and s_1 , s_2 , and s_n are their respective scattering coefficients; s is then the coefficient for the mixture, and W is the total grammage. The above relationship is based upon three assumptions:

1. Light scattering in a pulp-filler mixture is directly proportional to filler content.
2. Reduction in scattering through internal bonding is negligible.
3. The degree of optical contact between particles remains unchanged with changing density, and, therefore, s is independent of density.

3.6 While none of the above assumptions is entirely true, the deviations are slight in low-loading systems and the contributory scattering power concept has been used by many workers to establish specific scattering coefficients of various pulps and filler materials. Steele (6) was one of the first to do this and establish the s values for the more common pulps of the day. He arrived at the scattering coefficients of pigments by difference, thus:

$$s_{\text{pigment}} = [s_{\text{paper}} - (1 - y)s_{\text{pulp}}] / y$$

where y = the fraction of pigment in the paper.

3.7 It was immediately apparent that the s values of pigments in sheets, as obtained by Steele, would provide an excellent clue to pigment efficiency if the true (absolute) s values of the pigments were also known. Davis (7) attempted this by making sheets containing varied percentages of loading. He then plotted the s value of each sheet against filler content and extrapolated to the hypothetical sheet containing 100% filler and no pulp. His results were questioned because of assumptions 1 and 2 above. In high loadings the scattering of light in a sheet by a filler is not

directly proportional to the filler content by reason of the attendant materials which are used in flocculating the filler upon the cellulose fibers.

3.8 Adrian (8) developed a method for obtaining the absolute s values of pigments which he called the “film” method, as distinguished from the more commonly employed handsheet method. One of the most interesting aspects of his work is that he found this method particularly useful for measuring the influence of the compacting of pigment particles, particle size variations, and admixtures with other materials on the light scattering properties of pigment films. (See entire Adrian Thesis, Institute of Paper Chemistry, May 1942).

3.9 Recently, Biermann (10) has described how a computer spreadsheet can be used to customize the charts in this Standard Practice to focus on a small area for precise, graphical solutions that may apply to a particular grade of paper.

4. Example applications of the interrelationships

4.1 The interrelationships of the above optical properties can be used in a number of different ways. With ready access to computers, the use of the charts has largely been replaced by direct calculations. However, one useful application of the charts is to estimate sensitivity to measurement errors when working in different regions of the chart. Each of Figures 1 to 6 show that there are regions where the contour lines for R_∞ or sW get very close together. In these areas, result is sensitive to measurement errors and computer output should be used carefully.

4.2 Examples of two specific applications are described in the following sections: (1) opacity changes related to grammage changes, and (2) use of dye addition or removal to optimize the tradeoff between opacity and reflectivity. Another important application is the determination of optical performance of the coating layer for samples of coated paper. Clark and Ramsey (11) have provided procedures for that case.

4.3 With an opacimeter meeting the requirements of TAPPI T 425, measure any two of the following optical properties of a paper specimen of predetermined grammage:

$C_{0.89}$ TAPPI Opacity (see TAPPI T 425).

R_0 , the reflectance of a specimen backed with a black body (with the instrument adjusted to read zero with the black body in position and absolute reflectance with an absolute reflectance standard in position (see TAPPI T 425).

R_∞ , the reflectance (reflectivity) of an opaque pile of the specimen using the same distribution of light wavelengths as in T 425 (standard green filter).

4.4 With any two of these measurements, the third parameter can be determined by reference to the charts or by calculation with the equations below. Scattering power, sW , and absorption power, kW , can also be determined. Scattering and absorption power are dimensionless parameters. Dividing each by the grammage, W , gives the specific scattering coefficient, s , or specific absorption coefficient, k , which will have units of reciprocal grammage.

5. Procedure

5.1 Equations

5.1.1 From measurement of R_0 and R_∞

Eqn 1. $a = 0.5 (1/R_\infty + R_\infty)$

Eqn 2. $b = 0.5 (1/R_\infty - R_\infty)$

Eqn 3. $x = (1 - aR_0)/(bR_0)$

Eqn 4. $R_{0.89} = R_0 + [0.89(R_\infty - R_0) (1 - R_0 R_\infty)]/[R_\infty (1 - 0.89 R_0)]$

Eqn 5. $C_{0.89} = \text{TAPPI Opacity} = R_0/R_{0.89}$

Eqn 6. $sW = (0.5/b) \ln[(x + 1)/(x - 1)]$
 $s = sW/W$

Eqn 7. $kW = sW (a-1)$
 $k = kW/W$

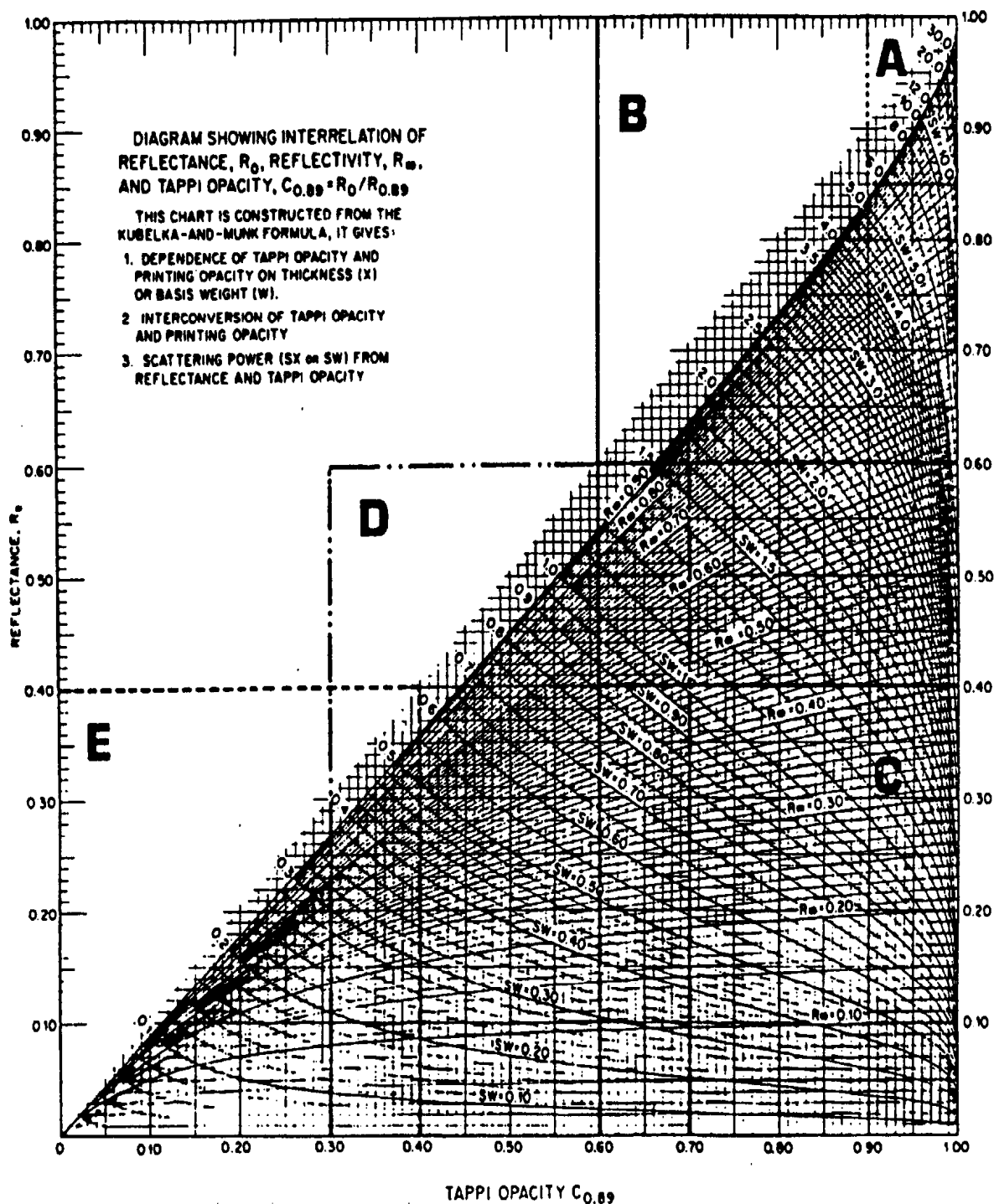


Fig. 1. Diagram showing interrelation of reflectance, R_0 ; reflectivity, R_∞ ; and TAPPI opacity, $C_{0.89}$. Areas are shown in more detail in Figs. 2-6.