

## ***IV. Preparation, Dyeing, and Finishing Processes***

### **16. Preparation and Drying**

Before dyeing and finishing a textile substrate, it (gricge or gray goods) must undergo preparation to assure complete wetting, uniform application of dye or finish, and/or to remove color or yellowness from the substrate that would interfere with coloration and the visual aesthetics of the textile. Fabric preparation includes wetting out of the fabric, scouring to remove natural waxes or spin finishes on the substrate, desizing to remove sizing from woven and warp knitted fabric, and bleaching to remove color (yellowness) from and to brighten the fabric. Natural fibers in the form of top, sliver, or yarn often undergo a degree of preparation prior to substrate formation. Following fabric preparation and dyeing or finishing, the textile substrate must be dried. Drying processes are currently under intense examination, since they account for nearly two thirds of the energy consumed in textile wet processing.

#### PREPARATION

In order to conduct the processes associated with preparation, the textile substrate must effectively be wet out. Surfactants or surface active agents are used to lower the surface tension of water in relation to the fiber substrate so the water will wet the substrate. Surfactants are organic molecules that effectively bridge the transition between water and the more hydrophilic fiber surface through combination of a polar head and a hydrocarbon tail within a single molecule.

Surfactants are also necessary for scouring processes in which surface waxes or spinning oils must be lifted from the fiber surface and suspended as micelles of oil surrounded by surfactant, followed by rinsing. Scouring processes are necessary to ensure complete removal of oil or wax from textiles so that dyes and finishes can uniformly penetrate the fiber and fabric structure. Low concentrations of sodium hydroxide in addition to detergent are used to scour cotton fabrics to assist in removal of their natural wax coating (Kiering). Scouring of wool is carried out in the fiber state prior to carding and spinning and is treated in Chapter 14. Sometimes additional scouring of wool substrates may be necessary to remove excess spin finishes or residual lanolin prior to dyeing and/or finishing. Use of solvent-based scouring techniques for synthetic fiber substrates has become more popular in recent years.

Sizing applied to warp yarns prior to weaving or warp knitting by the slashing process must be removed prior to dyeing or finishing to assure even and uniform application of the dye or finish. Sizes are not as readily removed as spin finishes and spinning oils, so special techniques must be used. Sizes can consist of starches, modified starches, and adhesives based on synthetic organic polymers. Starches and modified starches generally may be removed by dilute acid or enzyme treatment, whereas synthetic adhesive sizes can be removed by specialized short washing treatments.

Many natural fibers and some synthetic fibers possess a degree of yellow coloration and must be bleached to brighten and remove yellow coloration from the textile substrate prior to dyeing and/or finishing. Since bleaching is a chemical finishing technique, it is discussed in Chapter 18 under Optical Finishes.

## DRYING

After textile processes including sizing and desizing, scouring, dyeing, and finishing, the textile fiber substrate must be dried before further processing can take place or before the substrate can be delivered as the final product.

Wet textile substrates can be considered an irregular but somewhat ordered array of interlocking fibers making up a wet porous fibrous structure. Water within the structure lays between individual fibers being held by capillary action or by cohesive interactions between water molecules. Moisture is also present within the fiber depending on the moisture regain

characteristics of that fiber. In textile processes water not firmly held by capillary action or water within the fiber is removed by passing the substrate between squeeze rolls or by passing it over a narrow slit from which sonic velocity steam blows water from the fabric. Such processes can reduce the water uptake of the fabric to approximately 30 to 120% wet pick-up with sonic steam giving the lowest values. The water remaining then must be removed by convection, conduction, or radiation heating.

Drying of textile substrates is carried out most often by convection heating. The textile fabric under tension is passed into a convection oven heated to a temperature well above the boiling point of water. Hot air passing over the wet textile evaporates water from the fabric surface, and internal water moves by capillary and related actions to the fabric surface and in turn is evaporated. The resulting moist air is continuously removed as dry heated air is introduced into the oven. The tension devices holding the edge of the fabric remove wrinkles and introduce a uniform width to and tension on the fabric. These drying units are referred to as stenter or tenter frame dryers.

Conduction heating finds more limited use in drying of textiles and is used more in high temperature curing of finishes on textile substrates. In conduction heating, the textile fabric is brought in contact with and passed through a set of heated rolls. Since the fabric is in direct contact with the heated metal rolls, heat is transferred more quickly to the textile than possible by convection heating. The basic process of drying remains the same for both processes with heating of the outside of the textile structure, and drying from the outside to the interior of the structure.

In radiation heating, the wetted textile structure is irradiated by thermal radiation using a heat source such as an infrared lamp. On striking the wetted surface the radiation is absorbed and the surface is heated. Radiation heating has limited use for drying textile structures and is used more often in curing or pre-drying printed textiles.

Radio frequency and microwave energy can be used to heat wetted textile structures. The textile structure can be heated uniformly throughout, since water as a polar medium absorbs the energy. Radio frequency and microwave heating is efficient for initial drying, but as the moisture level decreases, there is less water to absorb the energy and the process is not as viable. Therefore, these processes are used in pre-drying fabrics and heating of wet packages.

In recent years the efficiency of drying textiles has been improved through insulation of the heating units and through installation of heat exchangers to remove heat from the outflow of warm moist air from the heating units.

## 17. Color, Dyes, Dyeing and Printing

### COLOR THEORY

Color is defined as the net response of an observer to visual physical phenomena involving visible radiant energy of varying intensities over the wavelength range 400 to 700 nanometers (nm). The net color seen by the observer is dependent on integration of three factors: (1) the nature of the light source, (2) the light absorption properties of the object observed, and (3) the response of the eye to the light reflected from the object. The relative intensities of the various wavelengths of visible light observed by the eye are translated by the mind of the observer resulting in the perception of color. In color measurement, the human eye is replaced by a photocell which detects the light energy present at various visible wavelengths.

Visible light is a narrow band of electromagnetic radiation from 400 to 700 nm (1 nm equals  $10^{-9}$  meters) detected by the human eye. Radiation falling below 400 nm is ultraviolet radiation, and that falling above 700 nm is infrared radiation; both are unseen by the human eye. If pure light of a given wavelength is observed, it will have a color corresponding to that wavelength. Pure wavelengths of light are seen when white light is refracted by a prism into a "rainbow" spectrum of continuous color. Light sources such as sunlight, incandescent light, and fluorescent light are continuums of various wavelengths of light with the relative amounts of the various wavelengths of light being dependent on the overall intensity and type of light source. Sunlight at noon has very nearly the same intensity of each wavelength of light throughout the visible spectrum, whereas at dusk sunlight is of lower intensity and has greater quantities of the

longer, red wavelengths than of shorter, blue wavelengths. Fluorescent lights generally contain large amounts of shorter, blue wavelengths, while incandescent tungsten lights contain a large component of longer, red wavelengths compared to noon sunlight. Differences in intensity and wavelength distribution between light sources has a profound effect on the color observed for a dyed textile, since the textile can absorb and reflect only that light available to it from the source. When a dyed fabric appears different in color or shade under two different light sources, the phenomenon is referred to as "flare." When two fabrics dyed with different dyes or dye combinations match under one light source but not under another, the effect is called "metamerism."

When light from a source strikes a dyed textile surface, different portions of the light of the various wavelengths are absorbed by the dye, depending of the structure and light absorption characteristics of the dye. Light not absorbed by the dye on the textile is reflected from the surface as diffuse light, and the observer sees the colors shown in Table 17-1. The color seen is a composite of all the wavelengths reflected from the fabric. If significant direct reflectance of light from the fabric occurs, the fabric exhibits a degree of a gloss. If little or no light throughout the visible range is absorbed by the fabric and the majority of light is reflected, the fabric appears white. If the fabric absorbs all of the light striking it, the fabric is black. If uniform light absorption and reflectance across the visible wavelengths occurs at some intermediate level, the fabric will be a shade of grey.

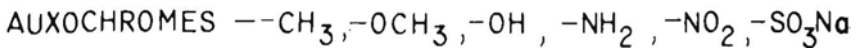
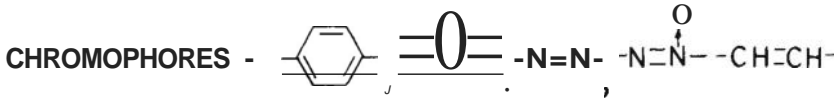
Table 17-1. Colors After Absorption/Reflectance

Wavelength of Light Absorbed (nm)	Light Absorbed by Dyed Textile	Color Seen by the Observer
400-435	Violet	Yellow-green
435-480	Blue	Yellow
480-490	Green-blue	Orange
490-500	Blue-green	Red
500-560	Green	Purple
560-580	Yellow-green	Violet
580-595	Yellow	Blue
595-605	Orange	Green-blue
605-700	Red	Blue-green

The dye absorbs discrete packages or quanta of light, and the dye molecule is excited to a higher energy state. This energy is normally harmlessly dissipated through increased vibration within the dye molecule as heat, and the dye is then ready to absorb another quantum of light. If the dye cannot effectively dissipate this energy, the dye will undergo chemical attack and color fading or color change will occur or the energy will be transferred to the fiber causing chemical damage.

Organic molecules that contain unsaturated double bonds are capable of absorbing light within a given wavelength range (usually in the ultraviolet). If these double bonds are conjugated and alternate within the molecule, they are able to mutually interact with one another as a cloud of  $\pi$  electrons. If sufficient conjugation exists, the molecule will partially absorb light in the lower energy visible wavelength range and will be considered a dye or a pigment. In general, dyes are colored molecules soluble or dispersible in water or solvent media which can penetrate the fiber on coloration, whereas pigments are not dispersible and must be mechanically entrapped in or locked to the fiber by a binding resin. A series of colorless dyes exist which are called "fluorescent brighteners." These dyes absorb little light in the visible region, but absorb radiation at unseen ultraviolet wavelengths and then emit this radiation at long blue wavelengths to provide an optical bleaching effect on fabrics. Fluorescent dyes combine fluorescence with visible light absorption characteristics to give extremely bright colors, since unseen ultraviolet light is also being made visible to the eye.

The unsaturated groups which can be conjugated to make the molecule colored are referred to as "chromophores." Groups which enhance or alter the color within a conjugated system through alteration of the electron density are referred to as "auxochromes." A series of typical chromophores and auxochromes follows:



The third component in color is the observer, which can be the human eye or a photodetector in a color instrument. Most color measurement systems are based on a standard light source and a "standard observer" for quantitative measurement of color. The human eye doesn't respond uniformly to color throughout the visible region, but gives maximum response in the middle visible wavelengths. In summary, then, the color observed is a composite of three factors, (1) the light source, (2) the object, and (3) the observer, which may be represented as in Figure 17-1. A change in any one of these three factors will affect the net color observed.



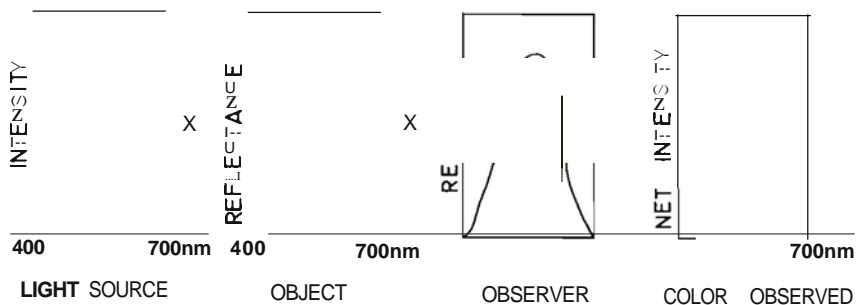


Figure 17-1. Observed color as a composite of three factors.

The color of a textile can be completely defined by the reflectance color spectrum of the fabric as seen above; however, since spectra are of limited value in defining given colors or shades, and numerical color systems have been developed to quantitatively or qualitatively define color. Knowing the relative position of two colors within the color space permits one to determine differences between the two colors. Color is often defined by the following terms: hue, chroma or saturation, and lightness or value. These color terms are defined as follows:

Hue -- basic color type (i.e., red, blue, green, etc.).

Chroma or saturation -- basic difference between color and the closest primary hue (i.e., difference between rose red and true red).

Lightness or value -- relative degree of lightness (i.e., degree of grey).

The Munsell system uses standard hues and numerical values for chroma and lightness to define color.

An array of chips of equal color difference as defined by many observers has been prepared that make up the Munsell Book of Color. The primaries consist of all major hues plus purple arranged logically to form a horizontal circle. The value or lightness makes up the vertical axis varying from 0 to 10 with 0 being black, 10 being white, and the intermediate numbers being varying shades of grey. The chroma is the degree of deviation from the "true" primary and can vary from 0 to 14, with the larger numbers being closest to the "pure" color. To determine the Munsell value for a given color, the Munsell color book is consulted to determine the color designation. For example, if a color had a designation of 5BG *SIB*, the sample would be a blue green with a value or lightness of 5 and a chroma of 8. In such a way color can be characterized, but it is not possible to assign strict numerical values to color differences between two dyed samples by use of the Munsell system.

Additive color systems used in color measurement determine the amount of three color primary lights necessary to define a given color using a standard light source and observer. Subtractive systems are used by dyers and colorists, since the net color reflected from a dyebath or dyed fabric is more meaningful in matching dyeings and depends on the amount of the three subtractive primaries present. Color theory and color measurement are complex and are further complicated by an individual's response to physical, physiological, and psychological aspects of color.

Nevertheless, color differences can be effectively measured using additive color systems provided the light source, the observer, and angle of viewing and degree of field observed is defined. In order to clarify and standardize the additive color system and color difference measurement, the Commission Internationale de l'Eclairage (CIE) was formed in 1931. The CIE has provided the definitions and standards necessary for color measurement. The primaries defined by CIE are not real colors, but are imaginary primaries used to define all colors in the color space. The amount of each of these primaries (tristimulus values  $X, Y, Z$ ) in a given color are used to define the shade and depth of shade for that color. Since the tristimulus values are difficult to plot, the values are normalized and reduced to trichromatic coefficients according to the equations  $x = X/X+Y+Z$  and  $y = Y/X+Y+Z$ . Then the shade of a sample is defined by  $x$  and  $y$ , and the relative lightness by the  $Y$  value which is equivalent to the total reflectance of the dyed textile as observed by the human eye. Color differences ( $\Delta E$ )

between two samples are determined by the equation  $\Delta E = (\Delta x^2 + \Delta y^2 + \Delta z^2)^{1/2}$ . The color space can be mathematically presented in a number of ways and numerous color difference formulas and systems exist.

Recently, the CIE has established a color and color difference system based on rectangular color coordinates called CIELAB. This system uses L rather than Y for lightness, since L is more closely related to the response of the human eye, with black being assigned 0 and white being assigned 100. A and B provide the shade value of the color in rectangular coordinates with A+ being red and A- being green, and with B+ being yellow and B- being blue. Then the equation  $\Delta E = (\Delta L^2 + \Delta A^2 + \Delta B^2)^{1/2}$  will give the color difference. Also cylindrical coordinates of L, C, and H, where L is lightness as defined above, C is the distance from neutral grey shade ( $C = A^2 + B^2$ ), and H is the arc tangent B/A expressed on a 360° scale where A+ = 0°, B+ = 90°, A- = 180°, B- = 270° may be used if desired.

The concentration of dye on a fabric after a given dyeing time can be determined by three methods: (1) measurement of the decrease in dye concentration in solution with time by ultraviolet-visible spectroscopy, (2) determination of the dye concentration on the fabric dyed for a given time by dye extraction and ultraviolet-visible spectroscopy, or (3) by measurement of the reflectance spectra of the dyed fabric followed by application of the Kubelka-Munk relationship in which  $K/S = \frac{(1-R)^2}{2R}$ . (K/S is the scattering coefficient and directly related to dye concentration, whereas R is the reflectance of the fabric at a wavelength of maximum absorption).

#### DYES AND DYE CLASSIFICATION

Dyes as colored unsaturated organic molecules must have affinity for fibers to be effectively applied. The dyes on fibers are physically bound to the fiber by one or more physical forces including hydrogen bonding, van der Waals, or ionic forces and in certain cases chemically bound by covalent bonds.

Dyes may be classified in a number of ways, including color, intended use, trade name, chemical constitution, and basis of application. Of these classification methods, chemical constitution and basis of application have been most widely used. Chemical constitution indicates the major chromophores present in the dye but does not indicate more than such structural aspects of the dye. A classification scheme for dyes has been developed and evolved for use by dyers which is based on the method of application

and to a lesser degree on the chemical constitution of the dye class. The classification scheme and major dye classes are outline below.

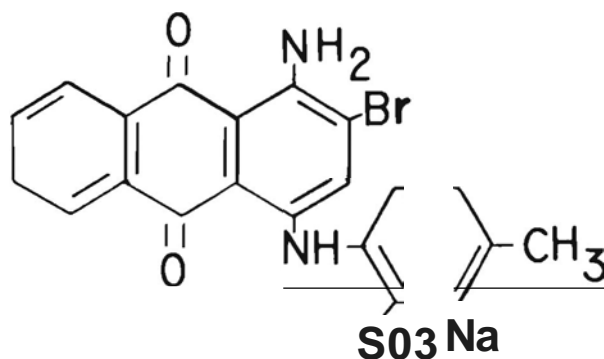
Dyes Containing Anionic Functional Groups	Dyes Requiring Chemical Reaction before Application
Acid dyes	Vat dyes
Direct dyes	Azoic dyes
Mordant dyes	Sul fur dyes
Reactive dyes	
	Special Colorant Classes
	Disperse dyes
Dyes Containing Cationic Groups	Solvent dyes
Basic dyes	Pigments
	Natural dyes

Dyes classified by this scheme are assigned standard designations according to dye class, color, and overall constitution by the Society of Dyers and Colorists in the Color Index (e.g" Acid Blue 141, Vat Green 17, Disperse Red 17).

#### Dyes Containing Anionic Functional Groups

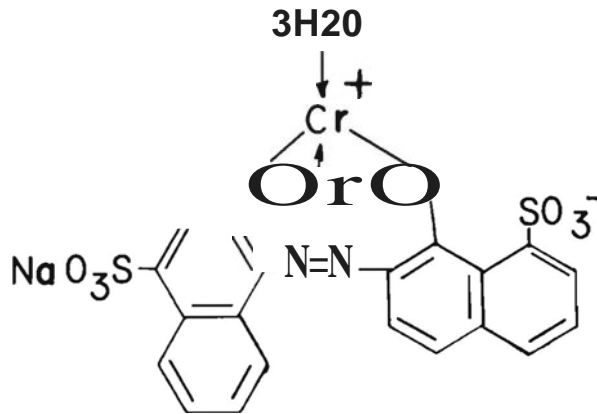
A number of dyes, including acid, direct, mordant, and reactive dyes, contain functional groups that are sodium salts of sulfonic or carboxylic acids. These functional groups provide water solubility to the dyestuff. The dyes differ in subclassification in their affinity for fibers and/or the presence of special functional groups.

Acid Dyes: The acid dyes are large dyes containing one or more sulfonic or carboxylic acid salt functional groups. These dyes are dyed onto fibers from acid solution, since positive charge development within the fiber in acid solutions acts as a driving force for dye diffusion and migration into the fiber. Only fibers which develop a positive charge in the presence of acid, such as wool, silk, and other protein fibers, nylon, and certain modified synthetics, are readily dyed by acid dyes. Acid dyes on fibers are reasonably colorfast to light and laundering, but mordanting (more complete insolubilization of the dye through reaction with a metal salt) will improve the overall fastness properties of the dye. The color of the dye may be affected somewhat by mordanting; however, pre-metallized acid dyes are a special class of acid dyes which have been reacted with a mordant prior to dyeing and which have sufficient solubility to be dyed under conditions normally used for acid dyes.



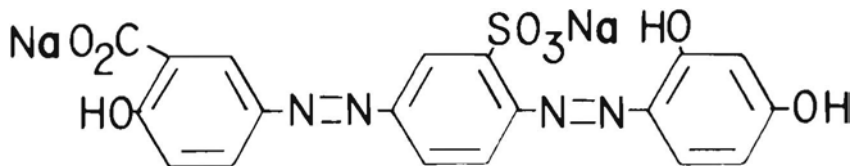
## ACID BLUE 78

One method of classifying acid dyes involves dividing them into three groups according to their application and wetfastness. Leveling acid dyes dye evenly to a moderate degree of fastness. For wool and protein fibers they are small molecules requiring highly acidic dyebaths for good exhaustion. For nylon, leveling dyes are somewhat larger molecules and are applied from weakly acidic dyebaths. Milling dyes have better washfastness, but generally give duller shades and lack good leveling characteristics. They are larger than leveling dyes and are applied from dilute acetic acid solutions. Acid milling or super milling dyes are applied from neutral solutions and have poor leveling characteristics due to their larger molecular size. They generally are applied to wool and have high wetfastness and lightfastness.



**ACID BLUE 158**  
**PRE-METALLIZED ACID DYE**

Direct Dyes: Direct or substantive dyes are a special class of dyes which penetrate cellulosic fibers readily and have good affinity for these fibers due to their size and shape. Whereas acid dyes are large and bulky, direct dyes are long, narrow, and flat in molecular structure, which allows them to readily enter the cellulose structure and interact with the cellulose in such a way as to provide good fiber affinity. Direct dyes often contain one or more azo groups connecting aromatic chromophores, thereby providing a straight chain dye molecule. Since charge development is not a primary consideration in diffusion of direct dyes onto cellulose, the dyes are usually applied from basic solutions in which cellulose is more stable and more likely to swell.

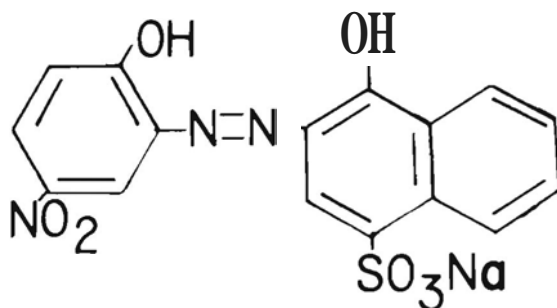


## DIRECT RED 185

Direct dyes fall into three main categories. Class A direct dyes level well even in the presence of high salt concentrations, while Class B direct dyes have poor leveling properties which can be improved by proper adjustment of salt concentration. Class C dyes have poor leveling properties, but exhaust well on raising the temperature of the dyebath in the absence of salt. The direct dyes are reasonably colorfast on cellulosic fabrics, but fastness can be improved by mordanting with metal salts, cationic fixing agents, or formaldehyde or through reaction with diazonium compounds or diazotization of the dye and reaction with a coupling compound.

Mordant Dyes: Mordant dyes are acid dyes that have special sites other than acid salt anion groups that can react with a metal salt mordant. Mordant dyes are "tailor-made" to chelate with metal ions to form a strong organometallic complex of limited solubility and greater colorfastness. The fiber may be dyed initially and then mordanted (postmordanting), dyed and mordanted simultaneously (comordanting), or mordanted and then dyed

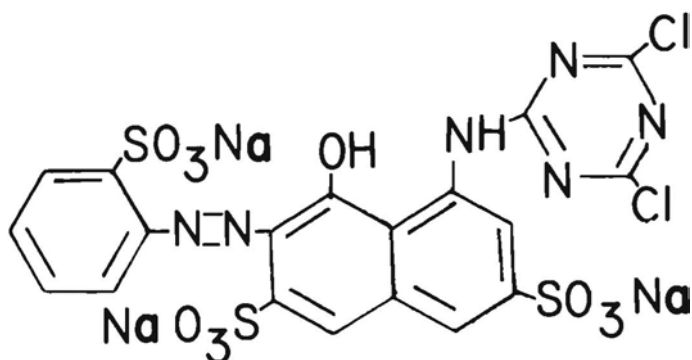
(premordanting). Of the three methods, postmordanting is preferred. Salts of chromium, aluminum, copper, iron, tin, and cobalt are commonly used as mordants. Since the mordant affects the electron distribution and density within the dye, the color of the dyed fabric tends to change.



## MORDANT BROWN 35

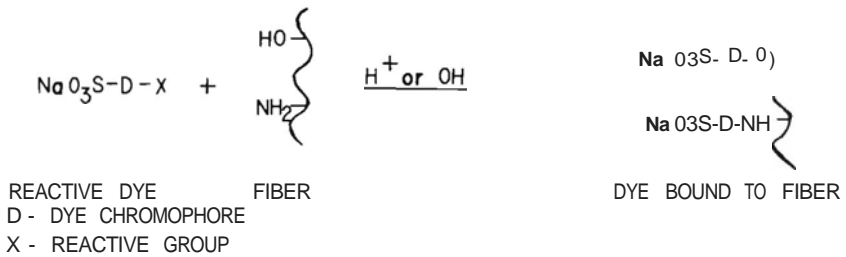
Reactive Dyes: Reactive dyes are dyes which usually have the basic structure of acid, direct, or mordant dyes but which in addition have a reactive group capable of covalent bond formation with the fiber. Since the fiber must have reasonable reactivity toward the dye reactive group, application of these dyes has been limited to cellulosic, protein, and nylon fibers for the most part.





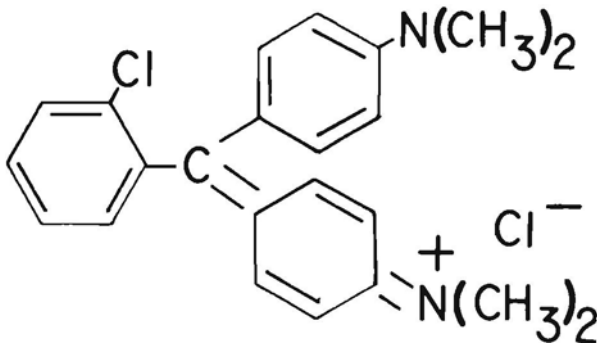
## REACTIVE RED

The fastness of reactive dyes covalently bound to the fiber is excellent. Reactive functional groups have been selected for incorporation into reactive dyes which will react readily with the fiber after diffusion into the structure but which will not hydrolyze (decompose) in the water solvent used in dye application. Acidic or basic conditions are necessary for successful and rapid reaction of the reactive dye with the fiber, so dye application is carried out at either slightly acid or basic pH (hydrogen ion concentration). Procion dyes are the best known of the reactive dyes.



Dyes Containing Cationic Groups (Basic Dyes)

Basic or cationic dyes are colored cationic salts of amine derivatives. Basic dye cations will migrate toward negative charges inside the fiber. The dyes may be applied to cellulosic, protein, nylon, acrylic, and specially modified synthetic fibers. Although the dyes generally are of striking brilliance and intensity, the colorfastness of the dyes on cellulosic, protein, and nylon fibers is generally poor. Colorfastness can be improved through mordanting with tannins or other complexing agents. Since the insoluble parent amine is regenerated from basic dyes at basic pH, the basic dyes are applied from mildly acid or neutral solutions. The dyes are also important in "one-shot dyeing" of paper products.

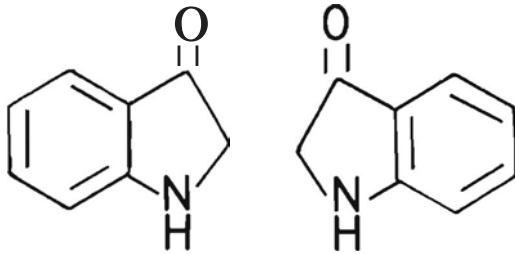


## **BASIC BLUE**

### Dyes Requiring Chemical Reaction before Application

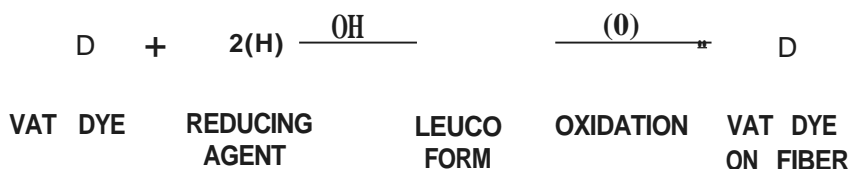
Both vat and sulfur dyes must be chemically reduced before application to a fiber, whereas azoic or naphthol dyes are formed through reaction of two separate dye components after application to the fiber. These dyes tend to penetrate the fiber less than other dyes, and care must be exercised in application to get reasonable fastness properties.

Vat Dyes: Vat dyes are usually water-insoluble dyes that can be chemically reduced in the presence of base to form a water-soluble and colorless leuco form of the dye, which is then applied to the fiber. Vat dyes can be readily applied to cellulosic fibers and most synthetic fibers, but care must be taken in applying the dyes to protein fibers due to the high basicity of the leuco dye solution which can damage protein fibers.



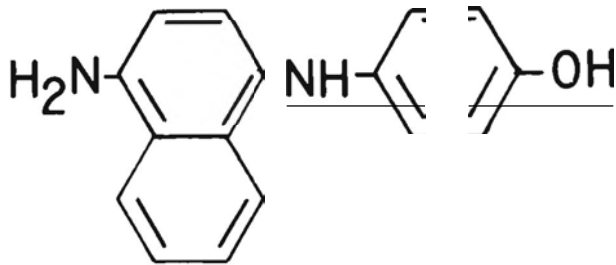
## VAT BLUE I INDIGO

The dyes are usually indigoids (such as indigo) or anthraquinone derivatives and applied at low ( $30^{\circ}$ – $60^{\circ}$ ) temperatures. After application of the leuco form of the vat dye, the dye is reoxidized on the fabric by oxygen in the air or through treatment of the dyed fabric with a mild oxidizing agent. The vat dyes are reasonably colorfast if poorly held surface dye has been removed:



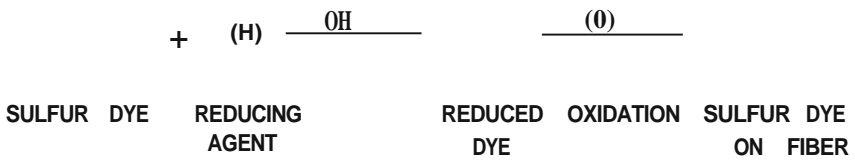
Stable sulfate esters of reduced leuco forms of vat dyes are available which do not require prior chemical reduction before application.

Sulfur Dyes: Sulfur dyes are inexpensive complex reaction mixtures of selected aromatic compounds with sodium polysulfide. The sulfur dyes are chemically reduced in the presence of base prior to application to the fiber, and are reoxidized after dyeing on the fiber by oxygen in the air or by application of a mild oxidizing agent such as hydrogen peroxide.



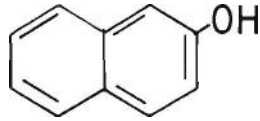
## SULFUR GREEN 6

The sulfur dyes are similar in application and fiber affinity to vat dyes, and also are available in a solubilized leuco form:

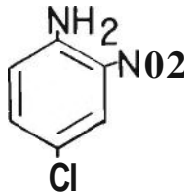


Sulfur dyes are inexpensive, and have adequate colorfastness properties for most applications.

Azoic Dyes: Azoic or naphthol dyes are formed in situ on the fabric through a coupling reaction of an aromatic alcohol or amine such as naphthol (the coupling component) with a diazonium salt (the diazo component). The dye formed contains an azo group:



## DIAZO COUPLING COMPONENT



## AZOIC DIAZO COMPONENT 9

The fabric is usually impregnated first with the aromatic coupling component followed by immersion of the fabric in a solution containing the diazo component, with the azoic dye being formed instantaneously. Owing to the instability of the components, the dyeings are carried out near room temperature. The dyes have moderate fastness, and dyeings may be mordanted to increase fastness.



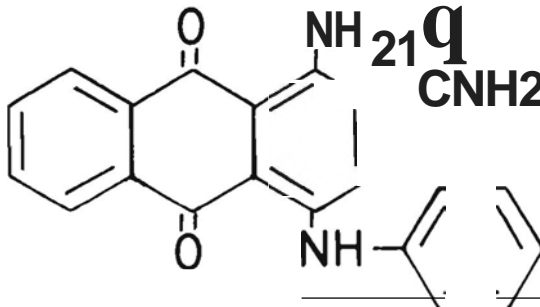


### Special Colorant Classes

Several types of dyes or colorants do not "fit" logically into the other classifications and have been included in this special classification. Disperse dyes are small polar dye molecules which can be used to dye thermoplastic fibers such as triacetate, nylon, polyester, and other synthetic fibers. Solvent dyes are dyes which are specially formulated so that they can be applied from solvents other than water. Pigments are not dyes at all, but rather colorants that must be incorporated in the fiber during spinning or fixed on the surface of the fiber by use of a polymer adhesive. Natural dyes are complex mixtures derived from natural sources which can be placed in a number of the above classifications.

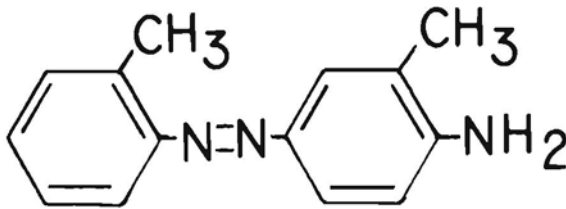
Disperse Dyes: Disperse dyes were formulated and introduced to permit dyeing of hydrophobic thermoplastic fibers including acetate, triacetate, nylon, polyester, acrylic, and other synthetics. The disperse dyes are

small polar molecules, usually containing anthraquinone or azo groups, which do not have charged cationic or anionic groups within the structure. The disperse dyes are sparingly soluble in water and must be dispersed with aid of a surfactant in the dyebath. As the small amount of dissolved disperse dye diffuses into the fiber, additional dye dispersed in solution is dissolved, until the disperse dye is nearly completely exhausted onto the fiber. A special class of reactive disperse dyes has been introduced that can react with fibers like acetate and nylon after diffusion into the fiber. The light- and washfastness of these dyes is generally good, but difficulty has been encountered with fume fading with certain of the disperse dyes. Many disperse dyes have appreciable vapor pressures at elevated temperatures and can be "dyed" onto thermoplastic fibers by sublimation, which involves diffusion of the dye vapors into the fiber.



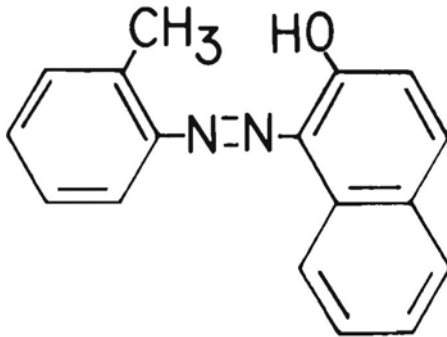
**DISPERSE BLUE 6**

Solvent Dyes: Solvent dyes often resemble dyes in other classes, except that these dyes contain groups that improve their solubility in solvents such as alcohols and chlorinated hydrocarbons. It is often possible with solvent dyes to dye certain fibers which would be poorly dyeable from aqueous solution.



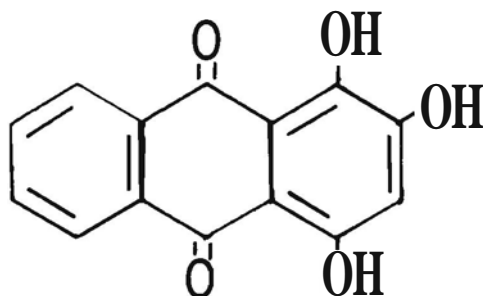
## SOLVENT YELLOW 3

Pigments: Pigments as a class are colored materials that are insoluble in their medium of application. As a result, they cannot penetrate or become readily fixed to a fiber and must be "locked" onto the fiber surface by use of a polymeric adhesive binder that encapsulates and holds the pigment onto the fibers. Pigments include inorganic salts, insoluble azo or vat dyes, toners, lakes, metallic complexes, and organometallic complexes. Some binders are preformed water-insoluble polymers applied from solvents or as emulsions, whereas others are water-soluble or emulsifiable polymers which can be chemically crosslinked and insolubilized after application by drying and heating. The pigment-binder systems tend to stiffen textiles, and have moderate to poor fastness, since they are surface treatments.



## PIGMENT ORANGE 3

Natural Dyes: Natural dyes and pigments are derived from mineral, animal, or plant sources and generally are complex mixtures of materials. A number of natural dyes can be classified as acid or vat dyes and can be readily mordanted. In general, the natural dyes give more muted tones than synthetic dyes and are useful only on natural or regenerated fibers.



## NATURAL RED 8

### PURPURIN

#### Dyeing of Blends

Textile structures are often blends of more than one fiber type. Blends containing similar fibers are easy to dye with dyes of similar structure and application characteristics. Care must be taken in dyeing blends containing fibers of highly different dye affinities, if the dyeing is carried out in the same dyebath. The dyes and their auxiliaries must be compatible with one another. When fibers in a blend are dyed the same color, the dyeing is referred to as "union dyeing," whereas dyeing fibers in a blend of different colors is referred to as "cross dyeing." In blends, interesting tone-on-tone, tone-on-white, and differential dyeings are possible by selection of appropriate dyes and dyeing conditions.

APPLICATION METHODS AND FACTORS AFFECTING DYEING

Dyes may be applied to textile structures in a number of ways and at a number of points within the textile construction process. Dyeing or printing techniques can be used. Dyeing methods involve application of dye solutions to the textile, whereas printing can be considered a specialized dyeing technique. In printing the concentration of dye is higher, and the dye medium is thick and viscous to limit dye migration on the fabric, permitting formation of a design or pattern.

Fiber or stock dyeing involves dyeing of the loose fibers or fiber top or sliver before yarn formation. Colorants can be added to man-made polymers before they are formed into fibers to ensure uniform coloration throughout the fiber. This technique is referred to as "solution" or "dope dyeing." Yarns or skeins can be dyed, and piece dyeing of textile fabrics can be carried out. Resist techniques such as tie-dyeing or batik limit dye migration to certain parts of the fabric. Discharge processes use bleaches or other chemicals to remove dye from selected areas of a dyed or printed fabric.

The above processes are used for application of dyes to textile substrates in the form of fiber sliver or top, yarn, or fabric by batch (discontinuous) or continuous methods.

Fiber or stock dyeing of sliver or top is usually conducted in large vats with movement of the dye liquor through the fibers to assure intimate contact of the dye liquor with the fibers. Yarn or skein dyeing is conducted by suspending skeins of yarn in an agitated dyebath with possible additional movement of the skeins during dyeing. Yarns can also be wound as packages on perforated spindles or spools and immersed in the dyebath. The dye liquor is then circulated back and forth through the packages. Fabric rolls can also be dyed by this package dye technique. Package dyeing is often carried out in closed systems at elevated temperatures and pressures. Jig dyeing involves passage of a fabric piece back and forth from one spindle to another through a dyebath, whereas a dye beck containing a winch is used to move a continuous fabric piece through the dye liquor. The above techniques are all batch processes.

The pad-batch method is a specialized batch technique for application of reactive dyes to cellulosic fibers. In the pad-batch method, cellulosic fabric is passed through a concentrated solution of reactive dye, followed by storage of the wet fabric in a vapor tight enclosure for 24 to 48 hours

at room temperature, to permit time for diffusion and reaction of the dye with the fabric substrate prior to washing off unreacted dye. The process leads to significant energy savings compared to conventional processes.

Various specialized techniques have been developed for application of disperse dyes to polyester. Unless the dyeing is carried out at 100°C or above, the rate of dyeing is very slow. Dyeing with disperse dyes from aqueous solutions at 120°-130°C to achieve rapid dyeings is common but requires the use of closed high-pressure equipment. Recently, jet dyeing has been introduced, which permits not only high-temperature dyeing but also impingement of the dye onto the moving fabric through use of a venturi jet system. Also, carriers can be introduced to permit dyeing of polyester at atmospheric pressure and below 100°C. Carriers are usually aromatic organic compounds that can be emulsified in water and which have affinity for the polyester. The carriers penetrate the polyester, open up the molecular structure of the fiber (often resulting in swelling of the fiber), and aid in passage of the disperse dye across the dye solution-fiber interface and within the fiber. Suitable carriers include aromatic hydrocarbons such as diphenyl and methylnaphthalene, phenolics such as *o*- and *p*-phenylphenol, halogenated aromatics such as the di- and trichlorobenzenes, aromatic esters including methyl salicylate, butyl benzoate, and diethylphthalate, and benzaldehydes. Carriers must be removed after dyeing, and the presence of carriers in mill effluents presents a problem because of their toxicity.

Continuous dyeing is carried out on a dyeing range where fabric or carpet is continuously passed through a dye solution of sufficient length to achieve initial dye penetration. The dye on the fabric or carpet is fixed by subsequent steaming of the substrate. Recently, foamed dye formulations have been applied to fabrics, thereby effectively reducing the dye liquor to fabric ratio and reducing energy and effluent treatment costs.

A novel approach to continuously dyeing polyester with disperse dyes involves sublimation of disperse dye under heat and partial vacuum into polyester by the technique called "thermosol dyeing." Polyester containing disperse dye applied to the fiber surface is heated near 200°C under partial vacuum for a short period of time. At this temperature, the molecular motion within the polyester is high, permitting the dye vapor to penetrate into the fiber. On cooling, the disperse dye is permanently trapped and fixed within the fiber. The above processes are graphically represented in figure 17-3.

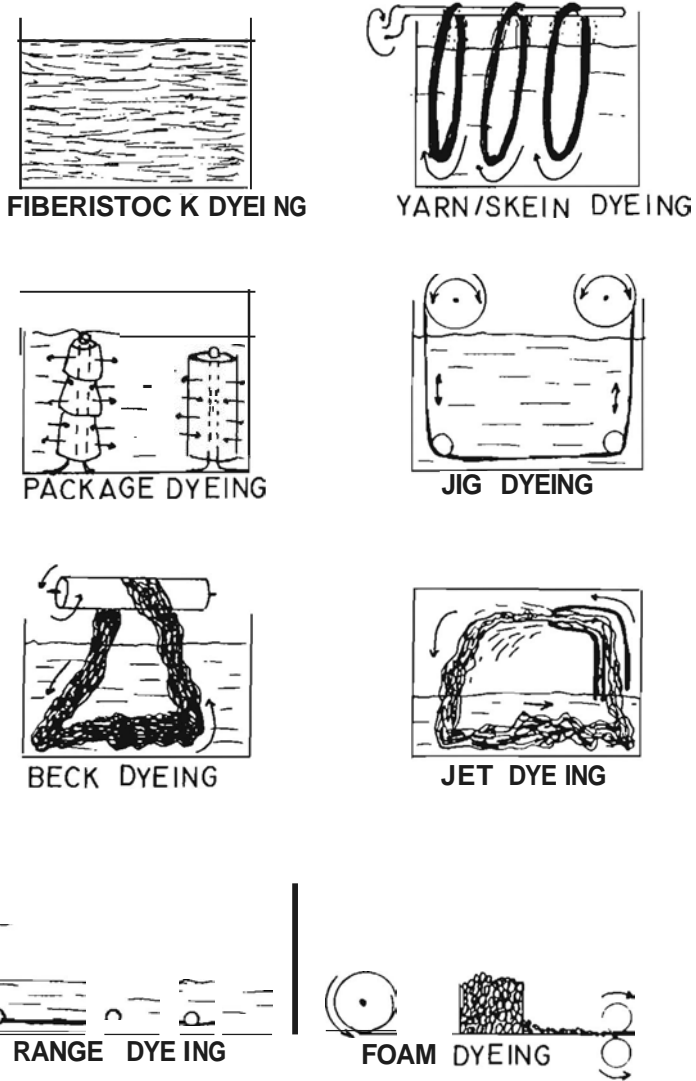


Figure 17-3. Dyeing processes.

In printing, the printing paste is applied through use of direct transfer dye using a block or engraved roller or through application using a partially marked flat or rotary screen and squeegee system.



Printing of polyester by disperse dyes can be accomplished by heat transfer printing, which is a modification of thermosol dyeing. In this process disperse dyes are printed onto paper followed by bringing the polyester fabric and printed paper together under pressure with sufficient heating to cause diffusion of disperse dyes into the polyester. Block, flat screen, and heat transfer processes are batch processes, whereas engraved roller and rotary screen printing are continuous processes. Special techniques using dyeing solutions which give printed style fabrics have been developed. In these processes, multiple jets of different dye solutions are sprayed in programmed sequence onto the fabric as it passes under the jets to form patterns with definition very nearly like that of prints. Specialized techniques for formation of patterns on carpets have been developed. In one process dye solution is metered and broken or cut into a pattern of drops which are allowed to drop on a dyed carpet passing underneath to give a diffuse overdyed pattern on the carpet. Representations of the printing and printed style processes are found in Figure 17-4.

Physical factors such as temperature and agitation and auxiliary chemicals added to the dyebath or printing paste can alter the rate of dyeing (dyeing kinetics) and/or the total dye absorbed by the fiber (dyeing thermodynamics). In dyeing, the rate of dyeing of the fiber is dependent on the rate of migration of dye in solution to the fiber surface, the rate of diffusion of dye at the fiber interface, and the rate of diffusion of dye in the fiber matrix. Agitation of the dyebath effectively eliminates the effect of dye diffusion to the fiber in the dyebath. The rate of dye passage across the fiber-liquid interface is rapid in most cases; therefore the rate of dyeing is solely determined by the rate of dye movement within the fiber matrix. As the temperature of dyeing is raised, the rate of "strike" of dye onto the fiber and diffusion in the fiber increases, whereas the total amount of dye present in the fiber at equilibrium decreases. In other words, heating a dyebath speeds dyeing but decreases the total dye exhausted on the fabric. Dyeing is usually carried out at a temperature above the glass transition temperature ( $T_g$ ) of the fiber, since the molecular segments of the polymers within the fiber have more mobility and permit more rapid dye diffusion above that temperature.

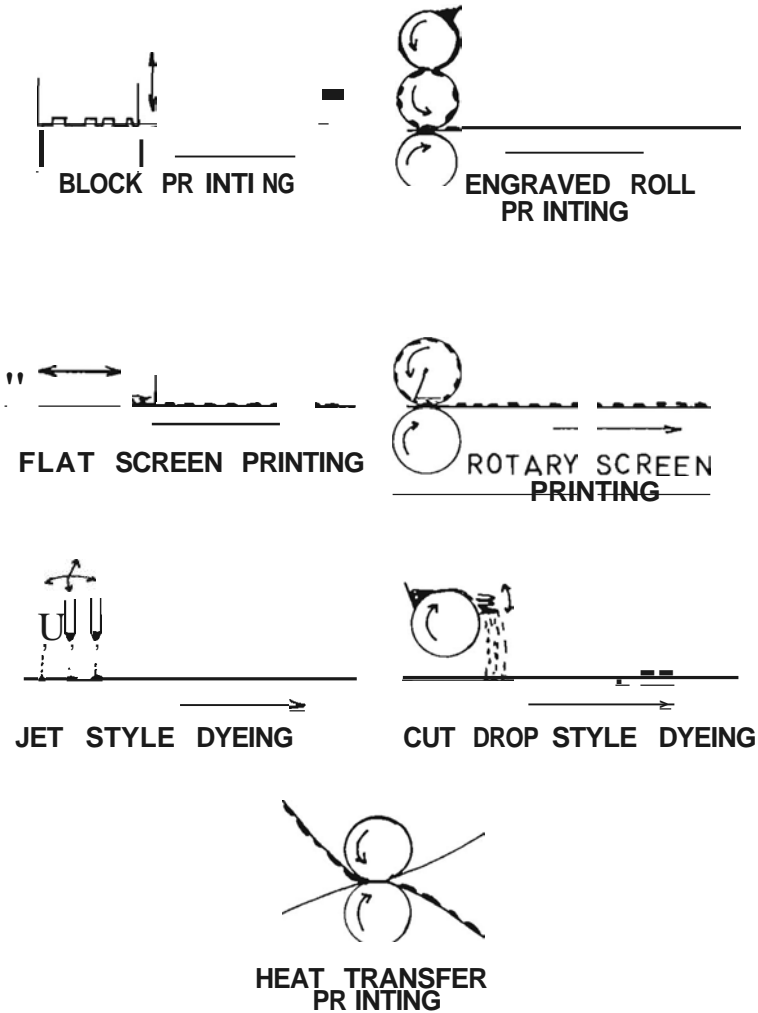


Figure 17-4. Printing and printed style processes.

A number of chemical reagents (auxiliaries) are added to the dyebath to alter in some manner the course of dyeing. Acids or bases may be added to the dyebath to induce charge formation in the fiber in order to increase dye diffusion or to promote reaction of the dye with the fiber as in the case of reactive dyes. In addition, bases may be used to open up the structure of cellulose to improve dyeing or to aid in dissolving of vat

and sulfur dyes. Common inorganic salts such as sodium chloride or sodium sulfate may be added to a dyebath and act as leveling agents to retard the rate of dyeing and give a more even dyeing. Surface-active agents such as anionic detergents can act as leveling agents and also permit the rapid and complete fiber wetting needed to give even dyeing. Water softening chemicals such as sodium hexametaphosphate are added to bind or chelate hard-water calcium or magnesium ions that may interfere with dyeing. Reducing agents are added to vat and sulfur dyes to react with the dye to give the leuco form. Added organic solvents and/or certain chemical reagents may increase the dye solubility and rate of penetration into the fiber. Carriers are aromatic derivatives added in disperse dyeings to open up the fiber structure of polyester and other thermoplastic fibers and to increase the rate of dye diffusion. Urea has a similar effect in speeding dyeing of cellulosic and protein fibers. In printing pastes, natural and synthetic gums and thickeners are necessary to provide viscosity and thickness to the dye paste and to limit dye migration across the fabric face. Heating of fabrics following printing is necessary to achieve good dye penetration into the fiber, and superheated steam is preferred, since wet fixation causes a faster rate of dye migration than dry heating methods.

The fastness of the dyeing will be dependent on the location of the dye within the fiber, chemical and physical forces holding the dye to the fiber, and the stability of the dye-fiber combination to environmental factors. Dye distributed evenly throughout the fiber in small aggregates is preferred, whereas surface or ring dyeing leads to poor washfastness.

## DYES APPLIED TO FIBER CLASSES

### Dyes for Cellulosic Fibers

Cellulosic fibers can be dyed readily using a number of dye classes. The less crystalline regenerated cellulose (rayon) dye more readily than the more crystalline natural cellulosic fibers such as cotton. Cellulosics can be dyed or printed using direct, reactive, basic, vat, sulfur, or azoic dyes. Cellulosics can also be colored using pigment-binder systems. Mordanting of direct and basic dyes on cellulosics improves overall fastness. Since the hydroxyl groups in cellulosics are less reactive than many functional groups found in protein fibers, reactive dyes such as the dichlorotriazine (Procion M) or dichloroquinoxaline (Levefix) dyes are often used on cellulosic fibers due to their higher reactivity. The general stability

of cellulosic fibers to basic solutions permits them to be effectively dyed by vat, sulfur, and azoic dyes without significant damage.

#### Dyes for Cellulose Ester Fibers

Acetate and triacetate fibers can be effectively dyed using disperse dyes. The rate of dyeing is more rapid with the more hydrophobic triacetate fibers than with acetate. Under special conditions, azoic and vat dyes may be used to dye these fibers. Acetate fibers also have affinity for selected acid and direct dyes. Since acetate loses its luster above 85°C, dyeings must be carried out at or below this temperature. Addition of pigments or solvent-soluble dyes to the acetate or triacetate spinning "dope" prior to fiber spinning leads to colored fibers possessing excellent colorfastness, although the colors available are limited.

#### Dyes for Protein Fibers

Protein fibers are the most readily dyed fibers due to the numerous reactive functional groups present. They can be dyed with a wide range of dyes under acid, neutral, or slightly basic conditions. Since the keratin fibers are less crystalline and oriented than secreted fibers such as silk, they tend to dye more rapidly and more readily to deeper shades.

Under acid conditions amino groups in the protein fibers are protonated to form  $\text{NH}_3^+$  groups. In this form, they are able to attract dyes containing acid anions including acid, direct, mordant, and reactive dyes. Special premetallized acid dyes of sufficient solubility are used to dye protein fibers to fast colors. The functional groups available in protein fibers are more reactive than hydroxyl groups in cellulosic fibers. Reactive dyes of more limited reactivity have been developed especially for protein fibers. Protein fibers complex very readily with multivalent metal cations. Acid dyes and mordant dyes may be rendered very fast by mordanting with metal salts, and chromium salts are especially effective as mordants. At neutral or slightly acid pH, protein fibers may be dyed with cationic or basic dyes; however, the fastness of the dyed fiber is poor without mordanting with tannic acid or other mordants for cationic dyes. Azoic and vat dyes find only limited use on protein fibers due to the damaging effect that basic solutions of these dyes have on protein fibers. Sulfate esters of reduced vat dyes can be used effectively on protein fibers, however. Natural dyes from many sources have good affinity for protein fibers and are used extensively in the crafts area and often in conjunction with mordants.

### Dyes for Polyamide Fibers

With the exception of the aramid fibers, the polyamides dye readily with a wide variety of dyes. Since the polyamides contain both acid carboxylic and basic amino end groups and have a reasonably high moisture regain, the fibers tend to dye like protein fibers such as wool and silk. Since the molecular structure is somewhat more hydrophobic, more regular, and more densely packed in the polyamides than in protein fibers, they also exhibit to some degree the dyeing characteristics of other synthetic fibers such as polyesters and acrylics. Due to their highly regular molecular structure and dense chain packing, the aramid fibers resemble polyester and are dyed only by small dye molecules such as disperse dyes. Polyamides such as nylon 6, 6,6, and Qiana can be readily dyed with dyes containing anionic groups, such as acid, metallized acid, mordant dyes, and reactive dyes and with dyes containing cationic groups such as basic dyes. Acid dyes on nylon can be mordanted effectively for additional fastness; however, the colorfastness of basic dyes is poorer and more difficult to stabilize by mordanting. Vat and azoic dyes can be applied to nylons by modified techniques, and polyamides can be readily dyed by disperse dyes at temperatures above 80°C. Aramids can only be dyed effectively with disperse dyes under rigorous dyeing conditions. The biconstituent fiber of nylon and polyester can be effectively dyed by several dye types due to the nylon component, but for deep dyeings disperse dyes are preferred. Nylon 6 and 6,6 are produced in modifications that are light, medium, or deep dyeable by acid dyes or specially dyeable by cationic dyes.

### Dyes for Polyester Fibers

Owing to their high crystallinity and hydrophobicity, the polyester fibers are extremely difficult to dye by normal dyeing techniques unless the fiber has been modified, as in the case of modified terephthalate polyesters. A limited amount of polyester is solution dyed through incorporation of dye or pigment into the polymer melt prior to spinning. It is more common to use this technique to incorporate fluorescent brightening agents into polyester. Only smaller, relatively nonpolar dye molecules can effectively penetrate polyester; therefore disperse dyes have been the dye class of choice for the fiber.

Azoic dyes and pigment-binder systems have also found limited use on polyesters. Polyester modified with appropriate comonomers can be dyed at lower temperatures or with acid or basic dyes depending on the nature of the modifying groups.

### Dyes for Acrylic Fibers

The nature and distribution of acrylonitrile and comonomer or comonomers in the acrylic fibers affect the overall dyeability and the classes of dyes that may be used in dyeing these fibers. Both acrylic and modacrylic fibers can be dyed using disperse dyes, with the more hydrophobic and less crystalline modacrylic being more dyeable with this dye class. The polar cyanide groups in the acrylonitrile unit of these fibers have some affinity for acid dyes and particularly mordanted systems containing copper or chromium ions. Addition of an acid or basic comonomer such as acrylic acid or vinyl pyridine as comonomer imparts improved dyeability with basic and acid dyes, respectively, for these fibers. Vat dyes can be used on acrylic fibers to a limited extent.

### Dyes for Polyolefin Fibers

Polyolefin fibers are hydrophobic, and the molecular chains within the fiber are tightly packed. Therefore it is extremely difficult to dye polyolefin fibers or to increase their affinity to dyes. Colored inorganic salts or stable organometallic pigments have been added to the polymer melt prior to fiber spinning to color the fibers. Also, nonvolatile acids or bases or materials such as polyethylene oxides or metal salts have been added to the polymer prior to fiber formation to increase the affinity of the fiber for disperse, cationic, acid, or mordant dyes. Polyolefin fibers can be chemically grafted with appropriate monomers after fiber formation to improve their dyeability.

### Dyes for Vinyl Fibers

The vinyl fibers, with the exception of vinal and vinyon-vinal matrix fibers, are extremely hydrophobic and difficult to dye, and consequently they can be dyed only through pigmentation of the polymer melt before fiber formation or through dyeing with disperse dyes. Vinal and vinyon-vinal matrix fibers dye readily with dyes used on cellulose including direct, mordant, reactive, vat, and sulfur dyes.

### Dyes for Elastomeric Fibers

Since the elastomeric fibers are often a component in the core of blended yarns, coloration is not important in all applications. Rubber fibers cannot be dyed readily and are colored through mixing of pigments into the rubber prior to extrusion into fibers. Spandex fibers are more

dyeable and can be dyed with acid, reactive, basic, or vat dyes. Anidex can be dyed with disperse or basic dyes. The nylon component of spandex-nylon fibers can readily be dyed with acid, basic, disperse, or vat dyes.

#### Dyes for Mineral and Metallic Fibers

The mineral and metallic fibers are essentially undyeable, and special techniques must be used to impart color to the fibers. Thermally stable ceramic pigments can be added to molten glass prior to fiber formation, or pigment-binder systems may be applied to the surface of the mineral and metallic fibers. Glass fibers can also be sized with a protein which then can be insolubilized and dyed with conventional protein dyes. Glass fibers are colored by coronizing, which involves preheating of the glass substrate to high temperatures to remove all organic materials followed by coloration with a pigment-binder system. The metallic fibers may also be colored through anodizing the metal (often aluminum) filament present or through pigmentation- of the plastic layer coating the metal. The nature of the metal in the organometallic fibers determines their ultimate color.

## 18. Finishes and Finishing

Often fibers in textile substrates are deficient in one or more properties, or improved properties are desired for the substrate. Textile finishing provides a method whereby deficiencies in the textile can be corrected or specific properties can be introduced. Physical finishing techniques (dry finishing processes) or chemical finishing methods (wet finishing) are used. Physical finishing is usually carried out on the yarn or formed textile substrate, whereas chemical finishes can be added to the spinning bath prior to fiber formation for man-made fibers or applied to individual fibers, yarns, or completed textile structures.

### PHYSICAL FINISHES AND FINISHING

Physical finishing methods for textiles include optical finishing, brushing and napping, softening, shearing, and compacting of the textile structure.

#### Optical Finishes

Luster may be imparted to a fabric by physical means. The techniques basically involve flattening or smoothing of the surface yarns using pressure. Beating of the fabric surface or passing the fabric between hard calendering rolls under pressure and with some friction will tend to flatten out the yarns and lower light scattering by the fabric surface, thereby improving reflectance and luster. Luster may be improved further if the calendering rolls are scribed with closely spaced lines which will be imprinted on the fabric to reinforce light striking and reflecting from the



fiber surface. Similar techniques can be used to impart optical light interference patterns to the fabric (*moiré*). Thermoplastic fibers which can deform under heat and pressure can most readily be modified to impart luster.

### Brushing and Napping

Physical delustering of a fabric as well as bulking and lofting of the fabric can be achieved by treatments which roughen the fiber surface or raise fibers to the surface.

Fiber raising processes such as brushing and napping involve use of wires or brushes which catch yarns in the textile structure and pull individual fibers partly from the yarn structure. The resulting fabric is warmer, more comfortable, and softer.

### Softening and Shearing

During calendering or beating of a fabric interaction between individual fibers within yarns may be lessened and the textile structure softened. Also, when a smooth textile structure free of raised surface fibers or hairiness is desired, the fabric may be sheared by passing the fabric over sharp moving cutting blades or by passing the fabric over a series of small gas jets which singe and burn away raised fibers.

### Compacting

During fabric formation processes, stresses often are introduced into a textile. Such stresses can be controlled by drying the finished fabric on a stenter frame, which controls the width of the fabric and the tension on the fabric during the drying process. A second method involves compression of the fabric structure, as in the Sanforizing process. In this process, the fabric and backing blanket (rubber or wool) is fed between a feed roller and a curved braking shoe, with the blanket being under some tension. The tension on the blanket is released after passing the fabric and blanket between the roller and braking shoe. The net result is compaction of the fabric being carried along in the system. Such a simple technique permits fabrication of the fabric of finished textile goods without fear of excessive shrinkage on laundering. Protein hair fibers such as wool, and thermoplastic fibers such as polyester, can be compacted by felting action. The scale structures on protein fibers entangle and stick on agitation, particularly in the presence of moisture. The resulting "ratcheting"

effect causes the fibers to compact and felt. Many processes for wool take advantage of this effect, and nonwoven felt structures are produced by this method. Compaction of thermoplastic structure occurs when the fibers are raised to near their softening point. At a sufficiently high temperature the fibers shrink and contract, causing compaction of the textile structure.

CHEMICAL FINISHES AND FINISHING

Chemical finishes are chemical reagents or polymeric materials applied to textile structures by a number of methods. The major types of chemical finishes used on textile structures are listed in Table 18-1.

Table 18-1. Major Chemical Finishes.

Finishes Affecting Aesthetics, Comfort and Service	Protective Finishes
Optical finishes	Photoprotective agents and antioxidants
Hydrophilic and soil release finishes	Oil and water repellants
Softeners and abrasion resistant fibers	Antistatic agents
Stiffening and weighting agents	Biologically protective finishes
Laminating agents	Flame retardants
Crease resistant and stabilizing finishes	

Chemical finishes can be applied by a number of methods including padding (immersion in the treatment solution followed by squeezing to remove excess), spraying, printing, foam application, or vapor techniques. In addition, the finish can be added to the spinning bath prior to formation of man-made fibers. Of these methods, padding is most important. Many finished fabrics must be dried (to remove solvent) and cured (heated to cause a chemical reaction) before chemical finishing is complete. Thorough wetting of the fiber by the finish solution and spreading of the finish evenly over the fiber surface is critical in most cases to get the desired effect. The location of the finish on the surface or within the fiber is important, depending on the finish and its function.

### Finishes Affecting Aesthetics, Comfort, and Service

Optical Finishes: Optical finishes do little to affect the color of a textile substrate, but rather act to destroy or mask color centers. They may either brighten the textile, making it more reflective, or deluster the textile, making it less reflective, depending on the treatment.

Bleaches are usually chemical oxidizing or reducing agents that brighten the textile by attacking unsaturated molecules that make the textile appear off-color. Chlorine bleaches such as sodium hypochlorite ( $\text{NaOCl}$ ) are strong oxidizing agents capable of destruction of color centers on a textile substrate. Unfortunately, sodium hypochlorite is fairly non-selective and attacks many dyes and finishes and certain fibers, causing loss or change in color and a deterioration in fiber properties. Sodium chlorite ( $\text{NaClO}_2$ ) and peracetic acid ( $\text{CH}_3\text{CO}_3\text{H}$ ) also are used as strong oxidizing bleaches on some synthetic fibers at the mill to achieve desired whiteness. Oxygen bleaches such as hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) and sodium perborate ( $\text{Na}_3\text{BO}_3$ ) are milder in oxidizing action and can be used on sensitive fibers such as wool. With hydrogen peroxide, pH adjustment is critical in getting the desired bleaching. Sodium perborate bleaching must be carried out at elevated temperatures, although chemical activators may be added to lower the effective bleaching temperature. Oxygen bleaches are less likely than chlorine bleaches to damage the fiber and dyes present on the fiber.

Reducing agents chemically reduce and saturate double bonds within color centers and find limited use as bleaches in mill applications. Reagents such as sodium dithionite ( $\text{Na}_2\text{S}_2\text{O}_6$ ) and sodium formaldehyde sulfoxylate ( $\text{NaHSO}_3\cdot\text{HCHO}$ ) are commonly used as reducing bleaches and in compositions for stripping dyes from fibers. Fluorescent brightening agents are colorless fluorescing dyes which mask yellow coloration on fabrics, and are discussed in Chapter 17.

Delustering of fibers may be carried out through alteration of the fiber surface or through addition of **alight** scattering and/or absorbing agent to the fiber substrate. Chemical attack or etching of the fiber surface leads to a more irregular surface morphology, thereby increasing light scattering and making the fiber dull. With man-made fibers, titanium dioxide ( $\text{TiO}_2$ ) is added to the spinning solution before fiber formation. Titanium dioxide is an excellent light scattering agent, and this delusterant is effective when added at 0.5%-2.0% levels to the fiber. Titanium dioxide can also be applied to the surface of natural fibers, **if** a binder

such as urea-formaldehyde resin is used to fix the delusterant to the fiber surface.

Hydrophilic and Soil Release Finishes: Hydrophilic (water-seeking) finishes that promote absorption or transport of water and aid in fiber wetting and soil removal in a textile construction are useful in many fiber applications. In man-made fibers surface-active agents such as nonionic polyethylene glycol derivatives can be added to the spinning solution prior to spinning, which will make the fiber more wettable and hydrophilic. Hydrophilic polymers such as copolymers containing acrylic acid can be fixed to fiber surfaces to provide improved water absorbency and to limit penetration of soils. Hydrolytic attack of the surface of hydrophobic man-made fibers such as polyester improves fiber wetting, moisture transport, and soil removal. None of the above absorbent techniques, however, are sufficiently effective to alter the absorbency properties of hydrophobic fibers like polyester enough to totally resemble naturally absorbent fibers like cotton and wool.

Softeners and Abrasion Resistant Finishes: Softeners and abrasion resistant finishes are added to textile structure (1) to improve aesthetics, (2) to correct for harshness and stiffness caused by other finishes on the textile substrate, and (3) to improve the ability of the fibers to resist abrasion and tearing forces. The softeners and abrasion resistant finishes are generally emulsions of oils or waxes, surface-active agents, or polymers that lubricate the surface of individual fibers in the textile substrate to reduce friction between fibers and permit them to pass over one another more readily. Emulsions of oils and waxes and related derivatives have been used in the past as softeners. Nonionic and cationic detergents act as softeners, but lack permanence. Emulsions of polyacrylates, polyethylene, or organosilicones impart softening properties and possess reasonable fastness. In addition, they may impart a more full hand to the textile.

Stiffening and Weighting Agents: Textile auxiliaries that stiffen and weight fabrics have included temporary and permanent sizes and metal salts applied alone or with a binding agent. The sizes stiffen the fabric through formation of bonds between fibers, particularly at fiber crossover points. Temporary sizes include starch, naturally derived gums, carboxymethylcellulose, and polyvinyl alcohol. Acrylic binders, polyvinyl chloride, and polyvinyl acetate emulsions act as permanent sizing agents. Metal salts may be used to weight certain fibers such as silk. If the metal salt has affinity for the fiber, as is the case for stannic chloride ( $\text{SnCl}_4$ ) and

silk, no binder is needed. Urea-formaldehyde or acrylic resins can act as suitable binders for fixation of nonpermanent metal salts onto the fiber surface. High intakes of metal salts used to weight textile structures may cause fibers to become brittle and to be sensitive to photochemically induced damage.

Laminating Agents: In recent years lamination of two textile structures together to form a composite structure has become very important. This technique requires use of adhesive materials that will not delaminate under normal use, including flexing and bending, shearing forces, and cleaning. The acrylics, polyurethanes, and a number of hot melt thermoplastic polymers are used as adhesives. Some adhesives have reactive groups which on curing lead to strong textile-adhesive covalent bonds in addition to the physical forces normally responsible for a good adhesive-fiber bond.

Crease Resistant and Stabilizing Finishes: When fibers are bent or deformed under various environmental conditions and then allowed to recover, the degree of recovery will depend on the morphology and inherent structure of the fiber. Most synthetic fibers show reasonable recovery from such deformation, whereas the cellulose and, to a lesser extent, the protein fibers have poor recoveries, particularly under moist conditions. Crease resistant finishes for cotton and rayon have been developed that give much improved wrinkle recovery properties, whereas crease resistant finishes for wool are still under development, since the process is complicated by felting shrinkage.

Crease resistant finishes for cellulose are chemical crosslinking agents and include wash-and-wear and durable press finishes. The wash-and-wear finishes are generally urea-formaldehyde or melamine-formaldehyde resins and are cured on cellulose as flat goods in the mill, whereas durable press treatments consist of cyclic urea-aldehyde derivatives which are partially cured at the mill, after which curing is completed after the fabric is made into a garment in apparel manufacture. Other difunctional finishes, including epoxides, isocyanates, vinylsulfones, and aziridines, have been introduced as crease resistant finishes for cellulose. These have met with only limited success owing to their higher cost and other deficiencies. Since wool is already heavily crosslinked, a different approach to crease resistant finishing must be taken. The disulfide crosslinks in the textile structures must be chemically reduced followed by a setting treatment with bifunctional reagents such as capped diisocyanate derivatives. Chemical treatments for setting of thermoplastic man-made

fibers are generally not used, since heat setting of these thermoplastic fabrics is an effective technique for imparting crease resistance. Urea-formaldehyde resins also are often used on cellulose to impart dimensional stability to the textile structure and to prevent yarn slippage within the structure. Finishes capable of causing interfiber bonding can act as effective stabilizing finishes, although they may stiffen the overall structure.

### Protective Finishes

Photoprotective Agents and Antioxidants: Oxidative attack of fibers by oxygen in the air is particularly enhanced by the presence of moisture and light and leads to overall deterioration of the fiber, its properties, and useful lifetime. Weathering of natural cellulosic and protein fibers is well known, and many man-made fibers rapidly deteriorate unless a protective agent is added to the fiber. Protective agents are applied topically to natural fibers or added to the spinning solution prior to man-made fiber formation. They are basically of two types, (1) photoprotective agents that interact with light and (2) antioxidants that quench oxidative free radical attack. Photoprotective agents interact with ultraviolet and visible light absorbing and/or scattering the light and often releasing the absorbed energy harmlessly as heat. Photoprotective agents include metal oxides such as titanium dioxide and tin oxide, various metal salts, and ultraviolet absorbing organic compounds. Ortho-substituted benzotriazoles, triazines, and benzophenones are aromatic organic compounds that can harmlessly transfer the absorbed energy within the aromatic ring structure and thereby dissipate the energy eventually as molecular vibration and heat. Antioxidants interfere with oxidative free radical reactions formed through quenching and/or removal of the free radical from the fiber matrix so that it will not react further. Antioxidants are usually heavy metal salts that interfere with oxidation or aromatic organic compounds such as phenols and thiol derivatives which can readily donate a hydrogen to the radical, forming a stable free radical species that will not react further. Such antioxidants present in fibers are eventually exhausted and thereafter can provide no further protection.

Oil and Water Repellents: Several classes of chemical agents exist that impart water and/or oil repellency when applied to textile substrates. Some finishes give water repellency only, whereas other finishes impart both water and oil repellency. Water repellent finishes are those which permit the fabric to continue to breathe after treatment, whereas waterproof treatments completely seal the spaces between individual yarns, as in

the case of rubberized or unsaturated fatty acid-cured fabrics (oil cloths). Older water repellent treatments used derivatives of soaps and fatty acids to impart water repellency. Owing to their hydrocarbon nature they exhibit no oil repellency and actually are somewhat oleophilic (oil seeking). Soaps combined with zirconium, aluminum, or rare earth salts and methylol or pyridium salt derivatives of fatty acids were the major water repellent finishes used prior to World War II. With the development of organosilicon polymers after World War II, the methylated polysiloxanes were introduced as water repellent finishes. Also, fluorocarbon finishes generally are preformed organic polymers that have fluorine groups substituted on the side chains. It is important that the fluorine constituents be present at the end of the polymer side chains, with terminal trifluoromethyl ( $\text{CF}_3^-$ ) groupings being most effective. The unique properties of fluorine that enable fluorocarbon polymers to repel water, oil, and waterborne soils have contributed greatly to their extensive use on consumer goods under trade names such as Scotchgard and Zepel.

**Antistats:** Antistats or antistatic agents are finishes that can be applied to a fabric to aid in the dissipation of static charge buildup on the fibers. Antistats can be applied to the fiber as a temporary finish or added in the spinning bath prior to fiber formation to give a more permanent finish. Chemical crosslinking of an antistat applied to a textile structure will provide a permanent finish, also. Most natural fibers and regenerated natural fibers are hydrophilic and possess charged or polar groups on the fiber surface that can dissipate static charge to the atmosphere and prevent static buildup. Therefore antistat treatments are confined to the synthetic fibers such as nylon, polyester, etc. The antistats are surface-active agents related to detergents, ethylene oxide derivatives, silicones, or polar polymers such as polyamine resins. Because of their polar nature, they are able to bleed static charge from the fiber and dissipate it into the air.

**Biologically Active Finishes:** Natural fibers and regenerated natural fibers are subject to attack by various biological agents including bacteria, fungi, and insects. While synthetic fibers are not normally attacked by these biological agents, substrates of these fibers can act as a support for growth of bacteria and fungi on the fiber surface. Several metallic and organometallic salts, phenolic and anilide derivatives, and quaternary amine salts can inhibit growth of bacteria and fungi on fibers. Cellulose most often require such treatment to prevent mildew and rot from feeding on and attacking the fiber substrate. Introduction of cyanide groups in cotton by graft polymerization of acrylonitrile on the substrate also

prevents attack by rot. In the past, commercial insecticides such as DDT and Dieldrin were used to prevent insect attacks on cellulosic and protein fibers. Since many of the insecticides previously applied can no longer be used for such treatments, new insecticides which are not environmentally persistent or damaging have been developed and are related to the natural products, the pyretherins.

Flame Retardants: All textile fibers with the exception of glass are flammable. The degree of flammability is dependent on the chemical structure of the fiber, the construction of the textile substrate, and the environmental conditions present at the time of fiber ignition. A fiber is flame retardant when it self-extinguishes on removal of the flaming source. Certain fibers, including wool, modacrylic, aramid, and vinyon, are flame retardant by virtue of their inherent chemical structure and combustion characteristics. Thermoplastic synthetic fibers such as nylon and polyester are not self-extinguishing and continue to burn after ignition; however, owing to their melt-drip characteristics, the molten flaming polymer drops away from the fabric, causing the fabric to stop burning. Other fibers, such as the cellulose, including cotton and rayon, burn readily and completely on ignition, leaving an ash which continues to oxidize and glow (afterglow) even after the flame is out. Blends of different types of fibers will show differing flammabilities which may not be directly related to an average flammability of the fibers in the blend. Flame retardants can be used on all fibers to improve their flammability characteristics further, with the most flammable showing the greatest degree of improvement on application of a flame retardant. Flame retardants for man-made fibers are generally introduced to the spinning solution prior to fiber formation, whereas natural fibers must be topically treated. Since the mechanism of flaming combustion of fibers varies with the fiber type, different retardants must be used for the various fiber types. The more flammable cellulosic fibers have received the greatest attention. Flame retardants can act in the gas phase or condensed phase of the burning fiber to interrupt oxidation and flaming and/or smoldering combustion. Organic compounds containing halogens (chlorine, bromine) and/or phosphorus, sometimes in conjunction with inorganic salts, have been found to be effective in many applications. Often different compounds in combination give a synergistic effect (an effect in excess of what might be expected from adding each component's contribution to flame retardation). Water-soluble inorganic salts containing phosphorus, boron, and ammonium have been found to be effective in "one-shot" nondurable applications, particularly on cellulose.



## FINISHES APPLIED TO FIBER CLASSES

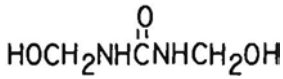
### Finishes for Cellulosics

Cellulosics have certain deficiencies in properties that require finishing to improve these properties and maximize consumer usage and acceptance. The most important cellulosic finishes include crease resistant and stabilizing finishes, soil release and softening finishes (in conjunction with crease resistant finishes), oil and water repellent finishes, biologically protective finishes, and flame retardant finishes.

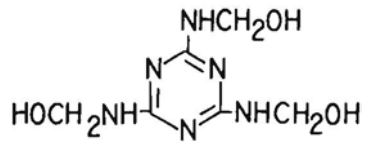
Crease Resistant and Auxiliary Finishes: Cellulosics characteristically do not recover well from bending deformation, particularly in the presence of moisture, and crease resistant finishes have been developed for cellulosics to improve the wrinkle recovery of the cellulosic fabrics in the wet and/or dry states. Such finishes also stabilize cellulosics against relaxation shrinkage induced by mechanical forces during fabric formation. The crease resistant finishes used for cellulosics are for the most part derivatives of urea and various aldehydes. These resins chemically crosslink adjacent cellulose chains and provide a chemical memory within the cellulose which aids in recovery from bending deformation or wrinkling. The degree of dry and wet wrinkle recovery of the resin-treated cellulosics will differ depending on whether curing to achieve crosslinking was conducted in the dry state or in the swollen wet state.

Although crease resistant finishes for cellulosics were developed shortly after World War I, it was not until after World War II that they appeared extensively on consumer goods. The finishes introduced in the late 1940s were generally referred to as drip dry or wash-and-wear finishes. The resin-treated cellulosics were cured flat while they were still moist at the mill. This required that the treated fabric be permitted to drip dry to achieve the maximum desired recovery effect. Since the fabric was cured in the flat state before being made into a finished textile, the garment did not retain creases placed in the finished garment. Flat set items such as sheets and table cloths can be effectively made crease resistant by this process, however. In the early 1960s durable press finishes were introduced. After resin application and partial curing at the textile mill, the treated fabrics were sent to the apparel manufacturer. The apparel manufacturer fabricated the treated fabric into garments which were then fully cured in their finished state to give a textile product that retained its creases and recovered to its finished form after washing and tumble drying.

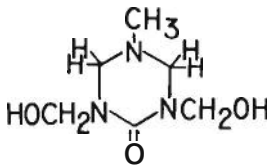
Although it is difficult to make a clear distinction between the resins used for the wash-and-wear and for durable press, certain generalizations can be made. Both types of resins are urea-aldehyde derivatives used in conjunction with possible other coreactants. The reactive functional groups in the resins are multiple N-methylol groups which undergo acid catalyzed reaction with hydroxyl groups in adjacent cellulose molecular chains to form bridging crosslinks to its unwrinkled state. Representatives of the major types of crease resistant resins for cellulose are shown below:



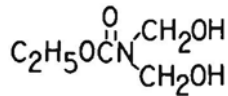
**DIMETHYLOL UREA**



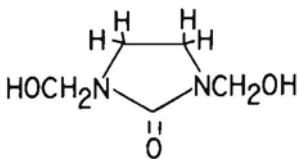
**TRIMETHYLOL MELAMINE**



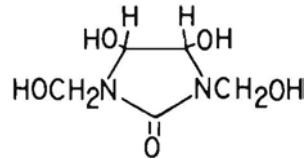
**DIMETHYLOL-N-METHYL-  
TRIAZONE**



**DIMETHYLOLETHYL -  
CARBAMATE**



**DIMETHYLOLETHYLENEUREA  
(DMEU)**



**DIMETHYLOLDIHYDROXY -  
ETHYLENEUREA (DMDHEU)**

In general, urea-formaldehyde condensates, N-methylolmelamines, and triazone-formaldehyde resins are used in wash-and-wear finishing. All suffer to varying degrees from chlorine retention and yellowing when in contact with sodium hypochlorite bleaches, which can cause damage to the cellulosic. In addition, the triazone resins give off a fishy odor under moist conditions. The ethyleneurea resins and the carbamates are used extensively in durable press treatments. In general, these resins are less susceptible to chlorine retention and undergo partial cure readily followed by a final cure. Latent or mild acid catalysts including inorganic and Lewis acid metal salts are added to the resin solution to achieve curing of all of these resins applied to cellulose. A gaseous formaldehyde-sulfur dioxide vapor treatment for 100% cellulose has been developed as well as a radiation curing treatment using N-methylolacrylamide. These resin treatments tend to lower the strength and overall abrasion resistance of the cellulosic fibers. Careful control of curing conditions and selection of catalysts as well as addition of softeners to the finishing solution can reduce this effect to some degree. Nevertheless, it has been necessary to blend thermoplastic heat settable fibers such as polyester with the treated cellulose to achieve acceptable wear characteristics. As a result polyester-cellulosic blends have made large inroads into markets where 100% cellulosic constructions were found previously. Soil retention on polyester-cellulosic blends treated with crease resistant resins has been a problem, and a series of polar hydrophilic soil release finishes have been developed to meet this need, as outlined before in this chapter. In recent years, low free formaldehyde durable press finishes have become important to protect workers from exposure to unreacted formaldehyde. In these formulations the methylol groups are capped with methyl groups, or a formaldehyde scavenger is added to the finishing solution.

Oil and Water Repellent Finishes: A wide range of oil and water repellent finishes are available for cellulose and are described earlier in this chapter.

Biologically Protective Finishes: Cellulose particularly used in outdoor conditions are susceptible to attack by microorganisms. Treatment of cellulose with chlorinated phenolic derivatives, organometallics such as copper 8-hydroxyquinolate, cationic surfactants, or grafting with polyacrylonitrile can reduce biological attack, although reductions in certain other properties may be expected.

Flame Retardant Finishes: Cellulosic fibers are among the more flammable fibers and are subject to rapid flaming combustion as well as slow

smoldering combustion. Flammability legislation and accompanying demand for flame retardant celluloseics over the last 25 years has resulted in development of a large number of flame retardant treatments for celluloseics, while only limited development of agents inhibiting smoldering combustion has taken place.

A number of temporary water-soluble flame retardant treatments for celluloseics are used. For the most part, these treatments use mixtures of inorganic salts, including borates, phosphates, silicates, and ammonium, and aluminum, antimony, and other metal ion salts. Borax and boric acid salt combinations are the most commonly used. Temporary flame retardants find only limited use on "one shot" items that will not be laundered. Permanent treatments are necessary for most celluloseic apparel and other celluloseics which must be laundered. Permanent treatments for nonapparel textile celluloseic substrates have involved antimony oxide in conjunction with chlorinated hydrocarbons and crease resistant nitrogenous resins or other resin binders. For apparel purposes, a number of resin treatments based on tetrakis(hydroxymethyl)phosphonium chloride (THPC) or on THPC plus sodium hydroxide (THPOH) have been used. THPC-amide based finishes include THPC reacted with trimethylolamine and urea or THPC reacted with urea and sodium hydrogen phosphate to form a complex polymer chemically fixed to the cellulose. THPOH-amide finishes include THPOH-urea-trimethylolmelamine and can be mixed with chlorinated hydrocarbons. THPC reacted in situ on the celluloseic with gaseous ammonia followed by mild oxidation has become a popular flame retardant finish in recent years. A dialkylphosphonamide, Pyrovatex CP, can be effectively cured on celluloseics when used with a triazine melamine resin to provide flame retardant properties. All of these flame retardant treatments result in some loss to the wear characteristics and aesthetics.

#### Finishes for Cellulose Ester Fibers

A limited number of finishes are used to correct deficiencies in acetate and triacetate. Delusterants, antioxidants, and/or antistat finishes as outlined previously are added to the spinning solution prior to fiber formation. Plasticizers (nonvolatile aromatic esters) can also be added to the spinning solution to improve the flexibility of the fiber. When flame retardant treatment is required, haloalkylphosphonates are added to the spinning solution or padded onto the yarns to effectively lower the flammability of these fibers.

### Finishes for Protein Fibers

Chemical Setting: Only limited finishing is carried out on protein fibers. Keratin fibers such as wool can be chemically set by chemical reduction of the disulfide crosslinks in the fiber, mechanically arranging the fiber in the shape (flat or creased) desired, and then reoxidizing and joining the cleaved disulfide bonds in the new configuration. Reducing agents commonly used are adducts of organic compounds with sodium dithionate ( $\text{Na}_2\text{S}_2\text{O}_6$ ) or sodium bisulfite ( $\text{NaHSO}_3$ ). The reduced disulfide (sulfhydryl) bonds are oxidized in time by oxygen in the air, but oxidation can be speeded up by application of a mild agent such as sodium bromate. This same process is used for permanent waving of human hair, which is also a keratin.

Shrinkproofing and Wrinkle Resistance Finishes: Wool and other keratin fabrics felt in the presence of moisture, agitation, and heat because of the surface scales on the fibers and resultant ratcheting action between individual fibers. Wool can be made resistant to felting shrinkage through modification of the scale structure by oxidizing the scales and/or by fixation of polymers on the scales. Oxidative treatments have included treatment by dry chlorination, wet chlorination, dichlorocyanuric acid, and permonosulfuric acid, as well as other oxidizing agents. The oxidizing agents attack the scales and partially destroy them, limiting their ability to cause felting. Although attack is mostly limited to the surface, significant damage and weakening occurs within the fiber. Polymer finishes that effectively can be spread and fixed on the fiber surface render wool shrink resistant even at uptakes as low as 1%-3%. Polymer is formed in situ on the fiber surface through reaction of step growth monomers such as diacid chlorides or diisocyanates with diamines (interfacial polymerization) or preformed polymers in solution or as an emulsion are applied to the wool and cured to chemically bond and fix the polymer to the wool. The presence of polymer on the fiber surface effectively prevents felting in a way that is not completely understood. The most satisfactory and effective treatments involve combined mild surface oxidation followed by polymer application. The usual shrinkproofing techniques have little effect on the wrinkle resistant characteristics of the wool. Finishes that contain chemically protected isocyanate groups have been developed that show some promise as durable press treatments for wool and have some ability to impart shrink resistant properties, too. Such treatments must be used in conjunction with chemical reduction of disulfide bonds in the fiber to set the fiber in the desired conformation in order to fully develop durable press properties.

Mothproofing Treatments: In the past, wool and other keratin fibers were protected from attack by moth larvae through use of mothballs (naphthalene or 1,2-dichlorobenzene) or chlorinated insecticides. In recent years, the chlorinated insecticides used have been banned, and less toxic organic insecticides have been developed for use on wool.

Weighting Treatments: Silk is characteristically weighted through chemical treatment to give a heavier fabric. Silk is treated with metal salts such as tin chloride in acidic aqueous solution followed by washing with sodium phosphate and sodium silicate to form a complex tin phosphosilicate. High levels of salt will impart a harsh hand to the silk and further lower its resistance to sunlight-initiated oxidative attack.

Flame Retardant Treatments: Although the protein fibers are naturally flame retardant, additional flame retardancy is required in some applications. Wool can be effectively rendered flame retardant through treatment with halogenated organic acids, organophosphonates, and complex inorganic salts of zirconium, titanium, tungsten, etc.

#### Finishes for Polyamide Fibers

Although the polyamides are strong, tough fibers, they possess deficiencies with regard to oxidative attack by oxygen in the presence of light and/or heat which necessitates finishing to limit such attack. Static charge buildup on nylon is also a problem, and antistatic treatments are often applied to the fiber. Improved flame retardancy is desirable in some applications, and flame retardant treatments are often used. Selection of appropriate comonomers can introduce groups into polyamides which alter their dyeing characteristics.

Photoprotective Agents and Antioxidants: Several approaches have been used to stabilize the polyamides against oxidative attack in the presence of heat and/or light. Application or addition of antioxidant compounds such as stannic chloride or aluminum chloride plus base, copper and manganese salts, tungstates and molybdates, substituted phenols, catechols, organic phosphites, and combinations of these materials to the polymer melt or as finishes have been found to be effective in preventing such attack. Ultraviolet absorbers such as benzotriazoles and hydroxyphenones are effective in preventing light-induced oxidative attack. Titanium dioxide added to nylon as a delusterant will lower the absorption of light by the fiber but will also contribute to light-induced photodegradation through peroxide formation.

Antistatic Agents: Polar hydrophilic polymers applied as finishes or added to the polymer melt prior to fiber formation improve the static buildup characteristics of polyamides. Polyethylene glycols and acid-containing vinyl and acrylic copolymers have been used, as have insoluble salts of amphoteric and cationic detergents.

Flame Retardant Finishes: Polyamide fibers can be most effectively flame retarded by thiourea-aldehyde condensate treatments in presence and absence of durable press finishes. Amino phosphorazines, ammonium bromide-binder combinations, and antimony oxide with halogen-containing polymers have also been found to be effective. Tris(2,3-dibromopropyl)phosphate (better known as Tris) is effective as a halogenated organophosphorous compound flame retardant, but due to its mutagenic and possible carcinogenic characteristics it has been excluded from use.

#### Finishes for Polyester Fibers

The major finishes for polyester fibers include photoprotective agents and antioxidants, antistatic agents, soil release finishes, antipilling finishes, and flame retardant finishes. Many of these chemicals can be added to the polymer melt prior to spinning. The finishes can also be added topically during dyeing and finishing.

Photoprotective Finishes and Antioxidants: Compounds that are used to stabilize polyesters against heat- and/or light-induced oxidative attack are similar to those used for nylon and other synthetics. They include metal salts as well as benzotriazoles, benophenones, and hindered phenols.

Antistatic Finishes: Owing to its hydrophobicity, polyester builds up static charge readily. Finishes have been developed for polyester that increase the hydrophilicity and ionic character of the fiber and permit more ready dissipation of static charge from the fiber surface. These treatments include lauryl phosphate, morpholine, various polyethylene glycols, organosilicones, and polyamine resins.

Soil Release Finishes: Owing to its combined hydrophobic and oleophilic character, polyester is soiled readily by oily soils. If these soils penetrate into the fiber, they are difficult to remove by laundering. In order to improve the removal of oily soils from polyester, oil repelling soil release finishes have been developed to limit the penetration of oily soils into the fiber, thereby making their removal easier during laundering. Perfluoroalkylamides and other fluorocarbon derivatives have been

used for this purpose, but more inexpensive hydrophilic finishes such as copolymers of acrylic acid, polyhydroxy compounds, and carboxymethylcellulose have been used more extensively. Since polyester is often used with cellulose in blends in which the cellulose must be treated with a durable press finish, combined durable press-soil release finishes have been prepared and are useful and very effective on such blends.

Antipilling Finishes: Because of its strength, polyester is subject to pill formation during wear. To make polyester more pill resistant, weaker and therefore less pillable, polyester fibers have been prepared by using lower molecular weight polymers or through partial hydrolysis of the polyester after textile substrate formation.

Flame Retardant Finishes: With the implementation of various flammability regulations in the U.S., improved flame retardant properties for polyester were required particularly with regard to the continued burning of melted polyester falling from burning fabric. In order to impart self-extinguishing characteristics to the polyester, two approaches have been used--introduction of halogen- and/or phosphorus-containing comonomers to the polymer structure or introduction of a halogenated phosphonate or related compounds to the melt prior to spinning. In both cases, antimony oxide may be added to improve the overall flame retardant characteristics.

Tris(2,3-dibromopropyl)phosphate (better known as Tris) was an ideal flame retardant for polyester and was used extensively for this purpose. Unfortunately, Tris was found to be mutagenic and a potential cancer-producing agent and had to be removed from the marketplace. As a result of the ensuing confusion, all topical flame retardant finishes have become suspect, and certain flammability requirements have been relaxed to allow polyester to pass the flammability test for children's sleepwear without further treatment.

Other Finishes: Comfort and the moisture related properties of polyester are of great interest, and finishes and treatments that improve these characteristics should be of great importance in coming years. Polyester fibers can be rendered more water wettable by surface treatment with basic solutions or through application of a hydrophilic finish to the polyester surface. Such finishes improve the water wicking and water transport characteristics of the polyester. Base hydrolysis has the added benefit of giving the polyester a crisp silk-like hand. Fine denier base-treated polyesters are produced in Japan that are effectively used as a silk substitute.



### Finishes for Acrylic Fibers

Antistatic treatments for acrylic fibers include polyglycol esters, fatty acids, and hydroxyl and amino derivatives that can be crosslinked with aldehydes or epoxy groups. Certain of these antistats as well as cationic surfactants can be used as softening agents to impart a softer hand to acrylic fibers. Modacrylics are flame retardant and self-extinguishing and usually do not require an additional flame retardant treatment. Acrylic fibers can be made flame retardant by use of a halogenated comonomer with acrylonitrile or through addition of an organic phosphorus derivative or halogenated material to the polymer solution prior to spinning.

### Finishes for Polyolefin Fibers

Antistatic finishes and antioxidants normally used on synthetic fibers are added to the polymer melt prior to polyolefin fiber formation. The most common antioxidants used include hindered substituted phenols, organometallic antioxidants, and substituted phenols. Blending of comonomers with polyolefin prior to fiber formation is used not only to improve dyeability but also to plasticize the fiber and improve other fiber properties. Polyolefins may be effectively made flame retardant through incorporation of a metal oxide such as antimony oxide in conjunction with a brominated hydrocarbon or brominated organophosphate.

### Finishes for Vinyl Fibers

Vinyl fibers except for vinal and vinal-vinyon do not generally undergo specialized finishing, although antioxidants and antistatic agents may be used. Vinal and vinal-vinyon matrix fibers can be treated with urea-aldehyde based durable press finishes to improve their wrinkle recovery, and vinal can be made flame retardant with phosphorus-containing finishes used for cellulose.

### Finishes for Elastomeric Fibers

The elastomeric fibers often have antioxidants and antistatic agents of the types outlined previously incorporated into them to protect the fiber against oxidative attack and to reduce static buildup, respectively.

Finishes for Mineral and Metallic Fibers

A limited number of finishes are used on mineral and metallic fibers. Glass fibers are often surface treated with agents such as chromium salts or silanes to improve their ability to adhere to organic adhesive materials used in polymer-glass fiber composites. Various organic starches, proteins, and synthetic polymer sizings are applied to glass fabrics to protect the individual fibers and to lower abrasion between individual fibers.