THE COLOR FASTNESS OF WOOL AND OF RAYON GABARDINE TO LIGHT, HEAT, AND DRY CLEANING

by

HAZEL MARIE SCOTT

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INTRODUCTION

The importance of rayon as a textile fiber is evident from the production in 1941 of 563,230,000 pounds of staple fiber and continuous filament. Of this, 51 percent was viscose and cuprammonium, 29 percent cellulose acetate, and 20 percent staple fiber (29). Since their invention in 1884, synthetic fibers have come into continually greater use until today the average consumer is faced with a difficult problem of fiber identification when she buys a fabric. Because of the many forms in which rayon can be produced, the resulting fabrics can be made to look like fabrics woven from any of the natural fibers.

Viscose and cuprammonium rayons are both regenerated cellulose; they burn like paper or cotton and can be ironed with a hot iron. Acetate rayon is a derivative of cellulose; it dissolves in acetone and melts or fuses when ironed with a hot iron. Continuous filament rayon is produced by forcing the spinning solution through a spinnerette; the resulting fine filaments of indefinite length are twisted together into a yarn that can be woven into a fabric. Staple fiber which has been in extensive use for the last 10 or 12 years is made by cutting the rayon filaments, after they have come from the spinnerette, into short fibers of equal length, usually one to six inches. These are then spun into yarns known as spun rayon. (8)

Rayons have long been woven into material which looked like wool. They have been sheer or heavy, creped or smooth. Recent developments have imparted to the acetate fibers even more of the characteristics of wool.

In 1938 the Eastman Acetate Company presented on the textiles market a cellulose acetate fiber with a permanent crimp. Up to this time attempts had been made to develop a viscose fiber similar to wool in surface roughness, but in none of these had the crimpiness been permanent.

Several methods were used to achieve crimp such as impregnating the viscose fibers with rubber or resins and then running them through fluted rollers; steeping the fibers in a solution of aluminum sulfate or calcium chloride which was heated strongly and then cooled quickly; or allowing the fibers to swell in sodium hydroxide after which they were steeped in a five percent solution of sulfuric acid, acetic acid or alcohol to cause shrinkage or swelling reduction (19). Crimp was introduced mechanically by an intermittent feeding of the spinning solution, by oscillating the spinnerette, by using buffer plates in the bath, by coagulating the spinning solution in snake-like pipes, or by cutting the wet and tensioned filaments (19). However, none of these treatments was permanent; the application of tension, steam or heat caused the fiber to revert to its ordinary straightness (5).

Teca, which is the name given to this new modified cellulose acetate fiber because it was developed by the Tennessee Eastman Corporation of America at Kingsport, Tennessee, not only has a permanent crimp, but is also resistant to crushing and creasing because of its resiliency. Its porosity and resilience add to its warmth as a fabric for clothing. Teca has a low affinity for moisture which makes it feel drier and dry more rapidly when wet than do the other rayon fabrics. It is decidedly free from shrinkage. (5)

Teca has advantages over wool in that it is not attacked by moths; it does not scratch or irritate sensitive skin; it can be laundered successfully; and it is less expensive than wool (26). The Teca fiber is supplied to the converter for two cents per pound above the price of regular acetate rayon staple (5).

As early as 1865 Schutzenberger and Franchimont were experimenting with cellulose, but the methods used were such that the resulting product was too brittle to be of commercial use. Soon after the beginning of the twentieth century the Dreyfus brothers in England became interested in cellulose and particularly in artificial silk made from cellulose. During the war their efforts were bent towards supplying cellulose acetate for waterproofing and tautening the fabric coverings of airplane wings. The Allied Governments became aware of its importance for war purposes, and the Dreyfus' received requests from France, Great Britain, Italy, and the United States to erect factories in those countries. Early in 1918 they started the erection of a factory at Cumberland, Maryland. This later became the headquarters of the Celanese Corporation of America. (6)

Following the war, many of these factories directed their efforts to producing cellulose acetate fibers to be used in weaving textile fabrics. One of the greatest problems faced by these manufacturers was to find a suitable dye to use. In this connection Dreyfus (6) said,

> Without Perkins' inventions and the indomitable energy with which he laid the foundations of the Synthetic Dyestuff Industry, I find it hard to conceive that the Synthetic Textile Industry could have developed to the stage it has today. Artificial silk is of no use unless you can dye it in a full range of colours and dye it cheaply.

Today there is a full range of colors applied to synthetic fibers and the cost of the fabrics remains low.

The purpose of this study was to determine the permanence of the dyes used on certain rayon fabrics by comparing the fastness of the colors on Teca and viscose rayon mixed materials with the fastness of colors on wool materials after they have been dry cleaned, heated, and exposed to light.

PRESENT STATUS OF KNOWLEDGE

Numerous studies have been made on the tendering effect of light and heat on all textile fibers, but apparently not much work has been done on the effect of light and heat on the color of the fibers.

Kertess (14) found that when cloth composed of white wool mixed with a dark dye was exposed to sunlight it became progressively darker. His theory was that the light attacked the white wool first, and because of its friable character, it fell away leaving the material darker. These changes, which required three to four months, were duplicated in much shorter time when ultraviolet light was used for the illumination.

Stirm and Rouette (25) reported that when wool which had been subjected to heat was examined under ultraviolet rays, it showed a greenish yellow fluorescence. Other findings which have been reported were that the most noticeable effect of heat on wool is the change in color, and that dry heat causes a gradual and continual change in wool (22). When wool is heated to a temperature higher than 100° C., a change in color generally occurs (16).

Although the studies so far mentioned have all reported damage due to light and heat, one writer stated that possibly the belief that high temperatures have a destructive effect on textile fibers was merely a prejudice which is hindering the discovery of useful new information. Perhaps new facts capable of forming the basis of entirely new treatments or possibly new industries are waiting to be discovered by anyone who will investigate the action of heat on textile fibers. (1)

Controversial opinions have been voiced with regard to the best methods of exposing colors to light and of measuring colors. Pierce (20) stated that the measurement of fastness to light is probably the "most inaccurate and misleading" of all textile measurements. Certain conditions that should not be permitted in truly scientific research cannot be avoided where artificial illumination is used. He further asserted that certain vat dyes and colors containing a nitro group react in different ways when exposed to actual sunlight and when exposed to rays from an electric arc. Another difficulty encountered by Pierce was the determination of the exact point at which fading began. He suggested that when "any dyestuff, in either a Fade-Ometer or sunlight test, had faded to such an extent that it was now equal to a 10 percent weaker dyeing of the same dyes, that this time should be taken as the proper figure for the test."

After making a test in an Atlas Fade-Ometer, in Florida sun and on a Shelton Roof under glass, Glenn (10) found that temperature or moisture content (or both) of the dyed fiber at the time of exposure altered the character of fade produced by fade testing machines. Also that similarity in the character of fade between an accelerated fade test and the official sun test is a matter of chance unless the moisture content and temperature of the fibers at the time of exposure are alike in the two cases.

Among those approving the use of artificial light or accelerated fading were Luckiesh and Taylor (15) who found that probably all dyed fabrics will fade to some extent when exposed to sunlight or to artificial light for a sufficient period of time. They thereby placed the responsibility for fading on the dyed material itself rather than upon the kind of light used. They attributed fading to the type, color, or concentration of dye, the fiber content, the method of dyeing, spectral distribution of incident energy, intensity and duration of illumination, and the temperature, humidity and purity of the air.

Fading was found to proceed more rapidly in the Fade-Ometer when the samples exposed were attached to cardboard than when fixed to the metal frames which are supplied with the Fade-Ometer. However, the Fade-Ometer was found to be equally reliably useful when either method was used to expose the samples. (27)

In considering the effect of light on fading on the specific fibers, wool was less affected than were silk or cotton (2). Little change in properties of the fibers was noticed when wool was exposed to sunlight; viscose was not strongly affected whereas acetate showed considerable sensitiveness (28).

Hermann (13), in speaking of the color fastness of spun rayons, said that fading is due to the finish of the material and to the treatment given by the user, rather than to the affinity of the fiber and dye. Many people expect spun rayon to look like the finer and more expensive silks, expect to pay little more for it than for a piece of cotton, yet treat it like cotton. It will not hold up under this treatment. The same degree of color fastness is obtainable on spun rayons as on other rayons, cottons, and linens if the dyer is permitted to use the methods and finishes necessary to guarantee this fastness.

Among acetates, even when fast colors have been used, fading has very often occurred. Recent investigations have shown this to be due, not to the action of sunlight, but to acid gases and other corrosion inhibiting compounds found in the air (17). Tennessee Eastman Corporation has developed "Chem. No. 199" for treating acetate fabrics to prevent this atmospheric fading; it is made available at a nominal cost to the finishers for fabrics made of Eastman acetate yarns (17). The A.A.T.C.C. Committee on Atmospheric Fading of Dyed Acetate Rayon reported that anti-fume finishes "cannot be considered as solving the fading problem" (11). It was the judgment of this committee that the gas fading problem can be solved satisfactorily only by the production of a new acetate rayon dye resistant to gas fumes.

No studies were found on the effect of dry cleaning on the color fastness of rayon or wool fabrics.

METHOD OF PROCEDURE

Materials

Nine viscose and cellulose acetate rayon mixed fabrics and nine all wool fabrics were used in this study. The yarns in the rayons selected were a blend of Teca and viscose fibers. Colors included white and light and dark shades of red, green, blue, and brown.

Selection of the fabrics from the two groups was made on the basis of similarity in weight, handle, appearance, and color. The white rayon was of plain weave; the colored rayons and five of the wools were of $\left(\frac{2}{1}\right)$ right twill weaves and the remaining four wools were $\left(\frac{2\ \ 1}{1\ \ 1}\right)_3$ right twills. The rayons were $0.65 per yard and were 39 inches wide with the exception of the white which was $0.50 per yard and 38½ inches wide. The wools varied in price from $3.45 to $3.95 per yard, and from 54½ to 59 inches in width. These materials were chosen from three wholesale establishments in New York, and one retail house in St. Louis. Mounted samples of these fabrics are shown in Plates I and II.

Physical Tests

The weave, thread count, twist, crimp, yarn counts, weight per square yard, and thickness were determined for each fabric.

EXPLANATION OF PLATE I

Teca and viscose mixed-rayon gabardines used in this study.

A Light red

B Dark red

C Light green

D Dark green

E Light blue

F Dark blue

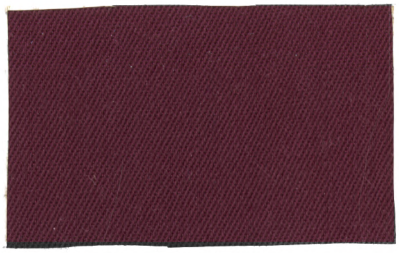
G Light brown

H Dark brown

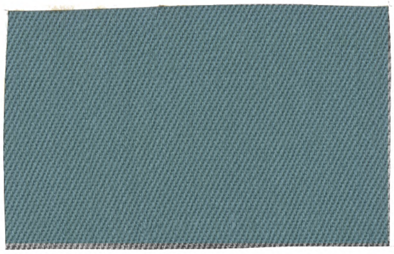
I White

PLATE I

A

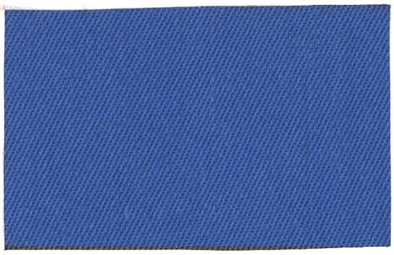


B



C

D



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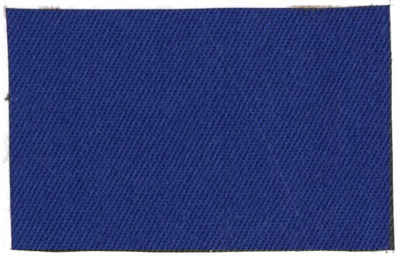

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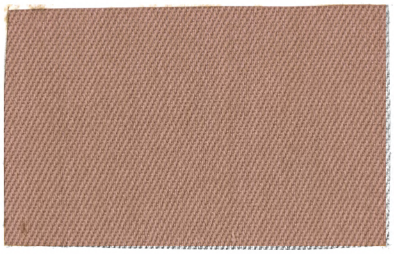
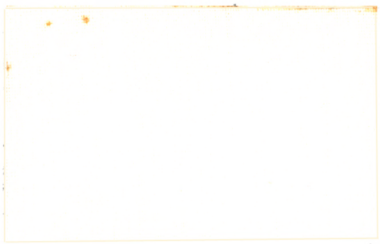


G

H



I

EXPLANATION OF PLATE II

Wool gabardines used in this study.

J Light red

K Dark red

L Light green

M Dark green

N Light blue

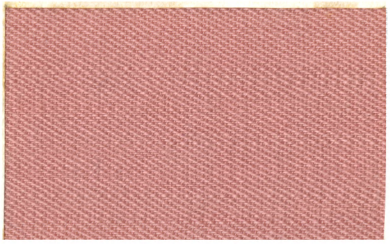
O Dark blue

P Light brown

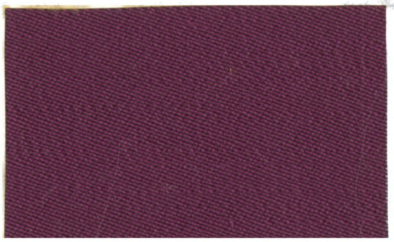
Q Dark brown

R White

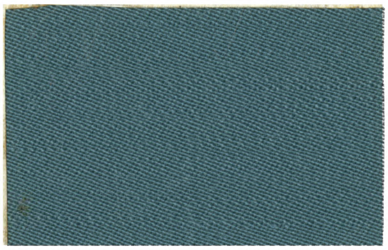
PLATE II



J

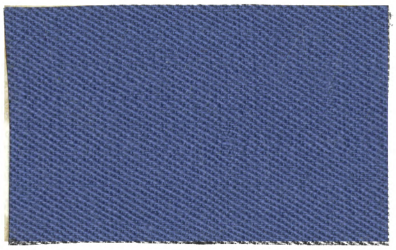


K



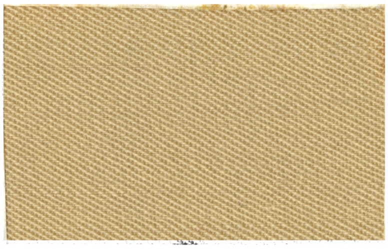
L

M

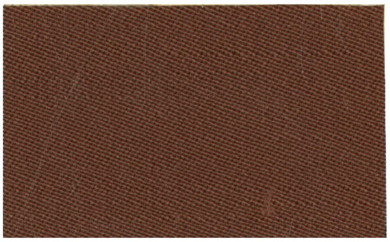


N

O



P



Q

R

The thickness, thread count and weight per square yard were determined by methods approved by Committee D-13 (4). To determine the crimp a Schwarz microscopic method with aid of a camera lucida was used (23).

The twist of the ply yarns was determined by inserting a 10 inch length of the yarn in the Suter twist counter and untwisting the yarn until the plys were parallel. Ten determinations were made for both warp and filling of each fabric with ply yarns, and the standard error was calculated. In determining the twist of the single strand yarn, a 10 inch length was placed under a known tension in the jaws of the twist counter and twisted until it was broken. A second piece of yarn of the same length was untwisted and retwisted in the opposite direction until ruptured. Ten determinations were made for the warps and fillings of each fabric with single strand yarns and the standard error was determined for N_1 and N_2. The twist was then calculated by the formula:

$$t = \frac{N_1 - N_2}{2 \times l}$$

where t = turns per inch
N_1 = number of turns to untwist and retwist to rupture
N_2 = number of turns to twist to rupture
l = length of yarn

The standard error of twist was determined from the partial errors of N_1 and N_2.

Yarn counts were found by drying to constant weight an eight-inch square of each fabric; after which the warp and filling yarns were raveled, counted and dried to constant weight. Any discrepancy which existed when the combined weight of the warp and filling was compared with the original weight, was divided equally between the warp and filling. The total length was calculated from the percentage crimp and the length of warp and filling yarns in the eight-inch square. The yarn counts were determined in the Typp system from these weights and total lengths. Weave and direction of twist were determined by observations.

Fiber Analysis

A quantitative analysis of the finishing material was made on each fabric by extracting the sample for two hours in carbon tetrachloride and then immersing in an aqueous solution of a starch and protein solubilizing enzyme preparation as outlined by Committee D-13 (4). Identification of the fibers was made from a microscopic study of longitudinal and cross section mountings. A quantitative fiber analysis was made on the rayon samples by dissolving the acetate in acetone and calculating the percentage loss in weight. This method is recommended by Committee D-13 (4).

Preparation of Material

Each fabric was divided into four parts: one was retained as the control and the others were given special treatments. One part was dry cleaned 30 times by the Manhattan Dry Cleaners, a commercial firm in Manhattan, Kansas, which is a member of the National Dyers and Dry Cleaning Association. The fabrics were cleaned in Stoddard solvent with Sanitone detergent and were pressed in a flat steam press. Although this is more dry cleanings than the materials would ordinarily be subjected to, the repeated cleanings were given to observe the trend of color change with dry cleanings.

The two remaining parts were cut into strips to be used in a subsequent study on breaking strength. Twenty strips lying along the warp and 20 lying along the filling were cut $1\frac{1}{4}$ inch wide and raveled to one inch. Ten strips on the warp and 10 on the filling from each fabric were exposed to light from a carbon arc lamp in the Atlas Fade-Ometer for 80 hours at 150° F. (65.5° C.) and with the humidity controlled. Exposure for one hour in the Fade-Ometer is equivalent to 1.3 hours of summer sunlight for textiles (21), or one Fade-Ometer day equals 10 June days. The remaining strips, 10 from the warp and 10 from the filling, were heated in the Precision Scientific Oven for 50 hours at 150° C. The results for these physical and chemical analyses of the fabrics are given in Table 1.

Color Analysis

Each of the treated and control fabrics was analyzed for color by the Bausch and Lomb HSB Color Analyzer. The attributes of hue, saturation and brilliance were calculated after an experimental determination of the sector percentages of two colors adjacent on the color wheel and of two neutrals. The formulas used to calculate these color specifications are given in Directions for Use of the Bausch and Lomb HSB Color Analyzer (3) as follows:

Table 1. Place of purchase, cost, physical characteristics, fiber content and finish of the nine wool and nine rayon fabrics tested.

Fabric	Place purchased	Cost per yard	Width	Crimp (percent) Warp	Crimp (percent) Filling	Twist per inch Warp	Twist per inch Filling	Yarn counts Warp	Yarn counts Filling	Thread count Warp	Thread count Filling	Thickness	Wt. in oz. per sq. yd.	Weave	Direction of twist	Fiber content (percent) Wool	Fiber content (percent) Acetate	Fiber content (percent) Viscose	Finish (percent)
A Light red Teca	Cheney-Brothers, New York	$0.65	39	12.4	11.7	25.2 ± .4	24.7 ± .2	19.6	18.9	106.4	58.8	.0187	5.4	$\left(\frac{2}{1}\right)_R$	Z		39	61	.6
B Dark red Teca	Cheney-Brothers, New York	$0.65	39	10.6	13.2	24.8 ± .4	25.6 ± .4	18.6	19.2	106.8	58.4	.0188	5.6	$\left(\frac{2}{1}\right)_R$	Z		39.4	60.6	.6
C Light green Teca	Cheney-Brothers, New York	$0.65	39	17.8	16.0	25.0 ± .3	25.6 ± .3	19.4	20.5	105.0	56.4	.0197	5.7	$\left(\frac{2}{1}\right)_R$	Z		39.4	60.6	.5
D Dark green Teca	Cheney-Brothers, New York	$0.65	39	14.4	7.4	25.0 ± .3	25.5 ± .5	18.6	18.0	109.6	58.8	.0194	5.6	$\left(\frac{2}{1}\right)_R$	Z		39.3	60.7	.4
E Light blue Teca	Cheney-Brothers, New York	$0.65	39	23.2	20.3	25.4 ± .5	25.7 ± .3	20.7	20.9	106.0	58.4	.0189	5.4	$\left(\frac{2}{1}\right)_R$	Z		39.4	60.6	.9
F Dark blue Teca	Cheney-Brothers, New York	$0.65	39	13.7	9.7	24.9 ± .3	25.2 ± .3	18.7	18.1	101.6	57.4	.0198	5.7	$\left(\frac{2}{1}\right)_R$	Z		39.4	60.6	.6
G Light brown Teca	Cheney-Brothers, New York	$0.65	39	16.9	13.8	25.4 ± .4	24.5 ± .3	19.3	19.9	107.0	57.2	.0190	5.4	$\left(\frac{2}{1}\right)_R$	Z		38.9	61.1	.6
H Dark brown Teca	Cheney-Brothers, New York	$0.65	39	11.0	14.4	25.4 ± .4	24.7 ± .3	18.7	19.5	106.4	59.8	.0193	5.5	$\left(\frac{2}{1}\right)_R$	Z		39.0	61.0	.6
I White Teca	A. M. Perlman, Inc., New York	$0.50	38½	19.6	23.6	15.2 ± .7	14.7 ± .6	21.2	22.5	72.4	59.0	.0156	4.1	$\frac{1}{1}$	Z		50.9	49.1	.8
J Light red wool	Welek's, St. Louis	$3.75	57	12.7	14.3	15.7 ±1.7	15.6 ±1.5	18.2	21.1	88.8	50.6	.0197	4.6	$\left(\frac{2}{1}\right)_R$	Z	100			2.0
K Dark red wool	Forstmann Woolen Co., Passaic, N. J.	$3.45	59	19.9	14.1	21.0 ±1.1	19.9 ±1.4	21.6	26.8	124.6	88.8	.0206	6.2	$\left(\frac{2\ \ 1}{1\ \ 1}\right)_{3R}$	Z	100			1.0
L Light green wool	Forstmann Woolen Co., Passaic, N. J.	$3.45	55	26.8	12.7	22.0 ±1.7	17.4 ± .8	21.4	25.4	122.8	95.4	.0234	6.6	$\left(\frac{2\ \ 1}{1\ \ 1}\right)_{3R}$	Z	100			.9
M Dark green wool	Welek's, St. Louis	$3.75	56½	7.6	6.1	14.7 ±1.6	16.5 ±1.5	17.7	18.9	88.4	48.4	.0186	4.6	$\left(\frac{2}{1}\right)_R$	Z	100			2.0
N Light blue wool	Welek's, St. Louis	$3.75	57	9.6	6.9	18.6 ± .9	16.4 ±1.0	18.3	20.8	88.4	52.2	.0191	4.6	$\left(\frac{2}{1}\right)_R$	Z	100			1.0
O Dark blue wool	Forstmann Woolen Co., Passaic, N. J.	$3.45	54½	17.0	8.1	23.6 ±1.0	18.8 ± .6	20.5	24.4	121.8	89.2	.0221	6.3	$\left(\frac{2\ \ 1}{1\ \ 1}\right)_{3R}$	Z	100			.8
P Light brown wool	Welek's, St. Louis	$3.75	57	21.6	7.8	18.5 ±2.0	15.6 ±1.6	20.0	20.1	90.8	51.8	.0202	4.6	$\left(\frac{2}{1}\right)_R$	Z	100			1.8
Q Dark brown wool	Forstmann Woolen Co., Passaic, N. J.	$3.45	55½	14.7	11.6	27.4 ±1.0	20.4 ± .7	22.2	26.4	120.6	88.0	.0209	5.9	$\left(\frac{2\ \ 1}{1\ \ 1}\right)_{3R}$	Z	100			1.6
R White wool	Welek's, St. Louis	$3.95	56½	10.5	15.9	14.4 ±2.4	18.8 ±1.8	17.4	20.2	90.2	50.8	.0202	4.8	$\left(\frac{2}{1}\right)_R$	Z	100			1.2

$$H \text{ (hue)} = z - \frac{Ax\ Px}{AxPx + AzPz} (z - x)$$

where x = number of first hue (clockwise in the hue circle)
z = number of second hue (clockwise in the hue circle)
A = area (expressed in sector percentage)
P = power number (brilliance x saturation)
H = resultant hue

$$S = \frac{A_1S_1 - A_2S_2}{100}$$

where S = saturation or chroma

$$B = \sqrt{\frac{A_1B_1^2 + A_2B_2^2 + A_3B_3^2 + A_4B_4^2}{100}}$$

where B = brilliance.

The color analyses for the control of fabric "A" and the same fabric after 30 times dry cleaned were calculated as follows:

Control of fabric "A"

Colors and neutrals			Areas
5	R	4/14	28
95	RP	4/12	29
	N	3	28
	N	4	15

$$H = 5 - \frac{29(4x12)}{29(4x12) + 28(4x14)} \times 10 = 0.28$$

$$S = \frac{(28x14) + (29x12)}{100} = 7.40$$

$$B = \sqrt{\frac{(28x4^2) + (29x4^2) + (28x3^2) + (15x4^2)}{100}} = 3.74$$

Color specification $0.28\ R\ \frac{3.74}{7.40}$

Fabric "A" dry cleaned 30 times

Colors and neutrals			Areas
5	R	4/14	28
95	RP	4/12	23
	N	3	34
	N	4	15

$$H = 5 - \frac{23(4x12)}{23(4x12) + 28(4x14)} x\ 10 = 0.86$$

$$S = \frac{(28x14) + (23x12)}{100} = 6.68$$

$$B = \sqrt{\frac{(28x4^2) + (23x4^2) + (34x3^2) + (15x4^2)}{100}} = 3.70$$

Color specification $0.86\ R\ \frac{3.70}{6.68}$

The color attributes for each of the fabrics were used in Nickerson's formula (18) to determine the indices of fading. This formula is:

$$I = \frac{C}{5}\ d2H + 6dL + 3dC$$

where I = index of fading
H = hue
L = lightness (brilliance)
C = chroma (saturation)
d = difference

The index of fading for fabric "A", dry cleaned 30 times, was calculated as follows:

Control of fabric "A" $0.28\ R\ \frac{3.74}{7.40}$

Fabric "A" dry cleaned 30 times $0.86\ R\ \frac{3.70}{6.68}$

Average Chroma	dH	dL	dC	I
7.04	.58	.04	.72	4.04

$$I = \frac{7.04}{5}\ 2(.58) + 6(.04) + 3(.72) = 4.04$$

$$I = 4.04$$

For two samples it was necessary to vary this method slightly and to determine the brilliance by imbalanced illumination. The samples of white were brighter than any of the standard discs, so the light above the sample stage was reduced until the N 9.4 disc placed there matched the N 7 disc placed on the disc stage. After the two fields had been matched, the sample "I", white rayon, was placed on the sample stage and the readings were made in the same way as for the colors. Hue and saturation were calculated as before. To introduce the differential of illumination into the equation in determining the brilliance, it was necessary to use the actual values for reflectance rather than the Munsell numbers. These reflectances, taken directly from the table in Direction for Use (3), are as follows:

Control of fabric "I"

Colors and neutrals			Areas	Reflectances
75	PB	6/6	13	.273
65	B	7/4	16	.389
	N	6	31	.273
	N	7	40	.389

Substituting these figures in the equations used for color gave:

$$H = 75 - \frac{16(7x4)}{16(7x4) + 13(6x6)} x\ 10 = 70.11$$

and

$$S = \frac{(13x6) + (16x4)}{100} = 1.42$$

The summation of the brightness-area products for the four discs gave:

$$R = \frac{(13x.273) + (16x.389) + (31x.273) + (40x.389)}{100} = .338$$

where R = reflectance of sample with imbalanced illumination.

The reflectance was converted into brilliance directly from the table.

$$\text{If} \quad R = .338$$
$$\text{then } B = 8.98$$

Specifications of fabric "I", control, were given as $70.11 \text{ PB } \frac{8.98}{1.42}$.

The other exception was fabric "O", dark blue wool, in which the reverse method was used because the sample was too dark to be matched with any standard discs. The light on the disc stage was reduced until the N 9.4 disc placed there matched the N 7 disc placed on the sample stage. The procedure after that was the same as for the white until the reflectance was converted to brilliance. Data for the sample "O", dark blue wool, are given below.

Control of fabric "O"

Colors and neutrals			Areas	Reflectances
65	B	2/2	11	.029
75	PB	2/2	16	.029
	N	1	56	.0112
	N	2	17	.029

$$H = 75 - \frac{11(2x2)}{11(2x2) + 16(2x2)} \times 10 = 70.93$$

$$S = \frac{(11x2) + (16x2)}{100} = .54$$

$$R = \frac{(56x.0112)+(17x.029)+(11x.029)+(16x.029)}{100} = .01903$$

Since there was no 7:9.4 brilliance ratio table for the conversion of reflectance into brilliance, the ratio of reflectance was calculated by $\frac{\text{reflectance of N 7}}{\text{reflectance of N9.4}} = \frac{.389}{.823} = .473$. The product of this ratio and reflectance gave R', the true reflectance of the sample, .473 x .01903 = .0090, which could be converted from the table.

If R' = .0090

then B = .83

Specifications for fabric "O", control, were given as 70.93 BP $\frac{.83}{.54}$.

The indices of fading were calculated by Nickerson's formula. Results of this analysis are given in Tables 2 and 3.

FINDINGS AND DISCUSSION

Statistical Analysis of Results

The analysis of variance (7, 24) was used to evaluate the data on color change. In the interpretation of differences by this analysis a five percent probability was regarded as significant, a one percent probability as highly significant, and 0.1 percent as very highly significant.

The data on indices of fading are given in Table 4. Using these indices the variances of the treatments were plotted against the means of the treatments. The resulting graph indicated a correlation, either curvilinear or a straight line. In a similar study, Hay (12) reported a graph with a straight line when five points were plotted. Since these indices did not form a normal population, each one was changed by using $I' = \sqrt{I + 0.5}$. This broke up the correlation between the variances and the means. These transformed indices are given in Table 5. The results of

Table 2. Color specifications for rayon fabrics.

Fabrics	Control	Treatments		
		30 x D.C.	80 hrs. light exp.	50 hrs. heat exp.
A Light red	0.28 R 3.74/7.40	0.86 R 3.70/6.68	3.69 R 4.90/7.86	7.67 R 4.20/7.42
B Dark red	1.43 R 1.46/1.68	1.43 R 1.46/1.68	1.08 R 1.67/2.76	1.43 R 1.46/1.68
C Light green	51.71 BG 3.96/2.38	53.57 BG 3.87/2.70	48.04 G 4.40/1.14	52.45 BG 4.08/1.96
D Dark green	39.46 YG 2.26/1.08	39.46 YG 2.26/1.08	38.43 YG 2.49/1.36	37.72 YG 2.34/1.08
E Light blue	66.43 B 2.67/2.50	66.15 B 2.71/2.58	65.84 B 2.79/2.64	68.03 B 2.53/1.98
F Dark blue	72.20 PB 1.95/2.72	72.20 PB 1.95/2.72	74.26 PB 2.22/2.72	73.18 PB 1.94/3.10
G Light brown	20.59 Y 4.18/3.72	20.22 Y 4.08/3.72	9.84 R 5.08/2.04	21.15 Y 4.44/3.20
H Dark brown	6.97 R 1.53/1.72	6.97 R 1.53/1.72	7.95 R 1.96/3.24	6.95 R 1.72/2.94
I White	70.11 PB 8.98/1.42	29.45 Y 8.35/1.89	70.11 PB 8.98/1.42	21.87 Y 7.97/3.32

Table 3. Color specifications for wool fabrics.

Fabrics	Control	Treatments: 30 x D.C.	Treatments: 80 hrs. light exp.	Treatments: 50 hrs. heat exp.
J Light red	98.72 PR 5.18/4.44	0.19 R 4.85/4.80	98.16 PR 5.28/4.48	14.34 YR 5.09/4.56
K Dark red	0.77 R 1.33/1.04	0.77 R 1.33/1.04	1.00 R 1.68/2.80	0.77 R 1.33/1.04
L Light green	61.28 B 2.80/2.42	61.28 B 2.80/2.42	59.12 BG 3.16/1.94	59.0 BG 2.74/2.10
M Dark green	49.64 G 1.44/.56	49.64 G 1.44/.56	49.83 G 1.72/1.16	50.14 BG 1.53/.74
N Light blue	70.26 PB 2.34/1.92	70.26 PB 2.34/1.92	68.40 B 2.86/1.84	70.80 PB 2.30/2.72
O Dark blue	70.93 PB .83/.54	70.93 PB .83/.54	73.64 PB 1.14/1.32	72.33 PB .93/.90
P Light brown	22.45 Y 5.20/2.52	21.72 Y 4.96/2.48	20.64 Y 4.78/2.80	22.70 Y 5.36/2.92
Q Dark brown	6.82 R 1.70/2.48	6.82 R 1.70/2.48	8.26 R 1.86/2.62	6.82 R 1.70/2.48
R White	61.27 B 8.66/.86	27.79 Y 8.20/2.15	24.53 Y 8.51/6.80	18.64 YR 7.25/6.00

Table 4. Indices of fading (I) of all fabrics after dry cleaning, and exposure to light and heat.

Fabrics	Treatments: 30 x D.C.	80 hrs. light exp.	50 hrs. heat exp.
Rayon:			
A Light red	4.04	18.75	24.72
B Dark red	0.00	4.81	0.00
C Light green	3.39	8.94	2.62
D Dark green	0.00	2.72	1.23
E Light blue	0.76	1.75	3.83
F Dark blue	0.00	3.86	2.04
G Light brown	1.15	22.82	3.89
H Dark brown	0.00	8.11	4.82
I White	32.19	0.00	57.44
Wool:			
J Light red	5.78	1.72	29.02
K Dark red	0.00	7.56	0.00
L Light green	0.00	5.48	3.38
M Dark green	0.00	3.54	1.21
N Light blue	0.00	4.75	3.14
O Dark blue	0.00	5.21	2.08
P Light brown	2.29	5.28	2.43
Q Dark brown	0.00	2.85	0.00
R White	26.72	75.01	82.37

Table 5. Transformed indices of fading (I'), sums, and sum of squares of indices of colored fabrics after dry cleaning, and exposure to light and heat. ($I' = \sqrt{I + 0.5}$)

Fabrics	30 x D.C.	80 hrs. light exp.	50 hrs. heat exp.	Sums
Rayon:				
A Light red	2.13	4.39	5.02	11.54
B Dark red	.707	2.31	.707	3.724
C Light green	1.97	3.38	1.77	7.120
D Dark green	.707	1.79	1.31	3.807
E Light blue	1.12	1.50	2.08	4.70
F Dark blue	.707	2.08	1.59	4.377
G Light brown	1.28	4.82	2.10	8.20
H Dark brown	.707	2.94	2.31	5.957
Sum of rayons	9.328	23.210	16.887	49.425
Wool:				
J Light red	2.50	1.49	5.44	9.43
K Dark red	.707	2.84	.707	4.254
L Light green	.707	2.44	1.97	5.117
M Dark green	.707	2.01	1.31	4.027
N Light blue	.707	2.29	1.91	4.907
O Dark blue	.707	2.39	1.61	4.707
P Light brown	1.67	2.40	1.71	5.78
Q Dark brown	.707	1.83	.707	3.244
Sum of wools	8.412	17.69	15.364	41.466
Sum of wools + rayons	17.740	40.900	32.251	90.891

Sum of squares = 235.886

the analysis of variance are given in Table 6.

Since the indices of fading for the white samples, in both rayon and wool, did not follow the trend of changes in the colored fabrics, their color changes in relation to treatments will be discussed separately. Had they been included in the analysis of variance they would have had undue influence on the results. The analysis which follows is based on the eight colored rayon fabrics and the eight colored wool fabrics.

The sum of squares was calculated by the following method:

Correction term: $C = \frac{(SX)^2}{n} = \frac{(90.891)^2}{48} = 172.10778$

Total: $SX^2 - C = 235.886037 - 172.10778 = 63.778257$

Fabrics: $\frac{(49.425)^2}{24} + \frac{(41.466)^2}{24} - C = 1.31971$

Treatments: $\frac{(17.740)^2}{16} + \frac{(40.900)^2}{16} + \frac{(32.251)^2}{16} - C = 17.120$

Colors within fabrics (variation within a group).

Correction term: $C_{(rayon)} = \frac{(49.425)^2}{24} = 101.78460$

Rayon fabrics:

$$\frac{(11.54)^2}{3} + \frac{(3.724)^2}{3} + \frac{(7.120)^2}{3} + \frac{(3.807)^2}{3} + \frac{(4.70)^2}{3} +$$

$$\frac{(4.377)^2}{3} + \frac{(8.20)^2}{3} + \frac{(5.957)^2}{3} - C = 16.949201$$

Correction term: $C_{(wool)} = \frac{(41.466)^2}{24} = 71.64288$

Wool fabrics:

$$\frac{(9.43)^2}{3} + \frac{(4.254)^2}{3} + \frac{(5.117)^2}{3} + \frac{(4.027)^2}{3} + \frac{(4.907)^2}{3} +$$

$$\frac{(4.707)^2}{3} + \frac{(5.78)^2}{3} + \frac{(3.244)^2}{3} - C = 8.219876$$

Table 6. Statistical analysis of fading for wool and rayon gabardines.

Sources of variation	Degrees of Freedom	Sum of squares	Mean squares	F (Remainder + fabrics x treat.)	F (Color within fabrics)
Fabrics (rayon, wool)	1	1.31971	1.31971	1.96293	
Treatments (D.C., light, heat)	2	17.12000	8.56000	12.73212***	4.76140*
Colors within fabrics	14	25.16908	1.79779	2.67403*	
Fabrics x treatments	2	.78211	.39105		
(Fabrics x treatments + Remainder)	30	20.16947	.67232		
Remainder	28	19.38736	.69241		

* 5 percent probability - significant.
** 1 percent probability - highly significant.
*** 0.1 percent probability - very highly significant.

Sum of squares for colors within fabrics = 16.949201 + 8.219876 = 25.169077

In obtaining the F-function for the first three sources of variation in Table 6, the mean squares of fabrics, of treatments, and of "colors within fabrics" would usually be compared with the mean square of the interaction term, "fabrics x treatments". However, in this study there was no interaction of "fabrics x treatments" and the sum of squares of "fabrics x treatments" was pooled with the sum of squares of the remainder to give a new mean square which was used as the error term. To get the error mean square the pooled sums of squares was divided by the aggregate degrees of freedom contributed by the two sources of variation as illustrated below:

$$\text{Error term} = \frac{.782109 + 19.387361}{2 + 28} = .6723156$$

This analysis of variance showed a non-significant difference between the two groups of fabrics, a significant difference between colors within fabrics of similar fiber content, and a very highly significant difference between treatments.

As a check against this method the mean square of "colors within fabrics" was then used as the error term for the first two sources of variation in Table 6. This also gave a non-significant difference between fabrics but the difference between treatments was significant.

The t-test on the arithmetic means was used in testing the differences between treatments. Table 7 shows the means for the t-test for treatments and Table 8 shows the least significant

Table 7. Totals and means of indices of fading (I') for treatments or wool and rayon.

Fabrics	Treatments		
	30 x D.C.	80 hrs. light exp.	50 hrs. heat exp.
Rayon	9.328 (8)	23.210 (8)	16.887 (8)
Wool	8.412 (8)	17.690 (8)	15.364 (8)
Totals	17.74	40.90	32.251
Means	1.11	2.50	2.02

Table 8. Least significant differences of means for treatment totals.

Difference for testing between	Probabilities (percent)		
	5	1	0.1
Treatments	.593	.798	1.06

differences between means for the five percent, one percent, and 0.1 percent probability levels used in the t-test.

The sampling variance used in determining the least significant differences between treatments, namely, dry cleaning, light, and heat, was in this instance the same as the error term. That is, the sampling variance was found by pooling the sum of squares for the colors within fabrics and the sum of squares of the remainder, and dividing by the pooled degrees of freedom.

$$V = \frac{.782109 + 19.387361}{2 + 28} = .672315$$

The variance of mean was found by dividing this sampling variance by the number of samples used in obtaining that mean.

$$\frac{V}{16} = .042 = V_{(\text{dry cleaning, light, heat})}$$

When the number of samples in the two means are equal then the variance of the difference between means is equal to the sum of the variances of the means.

$$V_{\bar{d}} = V_{\bar{x}_1} + V_{\bar{x}_2}$$

$V_{\bar{d}} = .042 + .042 = .084$, variance of difference between dry cleaning and light, between light and heat, and between heat and dry cleaning.

The square root of the variance of difference between means gives the standard deviation of the difference, $s_{\bar{d}}$.

$s_{\bar{d}} = \sqrt{V_{\bar{d}}} = \sqrt{.084} = .290$ = standard deviation of the difference between dry cleaning and light, light and heat, and heat and dry cleaning. This formula was then used to obtain the least significant differences.

$$t = \frac{\bar{d}}{s_{\bar{d}}} \quad \text{or} \quad \bar{d} = t \times s_{\bar{d}}$$

where $\bar{d}$ = least significant difference between means
$s_{\bar{d}}$ = standard deviation of difference between means
t = value taken from table of distribution from Fisher-Yates (7).

The t-test showed a very highly significant difference between the effect of dry cleaning and light; a non-significant difference between light and heat, and a highly significant difference between heat and dry cleaning. Thus the differences in fading due to treatments were greater than the difference between the two groups of fabrics.

Comparison of the Color Changes of the White Wool and the White Rayon

For the white samples it was advisable to make a separate comparison, because in both the wool and rayon groups the whites did not follow the trend in color changes of the dyed fabrics.

The white was the only one of the rayons which did not fade when exposed to light; no color change was noticed after it had been exposed to light in the Fade-Ometer for 80 hours. Fletcher and Houston (9) in 1939 found the color changes in white rayons exposed to light so slight that no definite conclusions could be drawn as to which type of rayon faded most. The white wool, "R", was decidedly yellow after 80 hours exposure to light. Glenn (10) found in recent research that undyed woolen swatches yellowed badly in the Fade-Ometer at 140° F., but they yellowed only appreciably at 105° F. The temperature in this experiment was maintained at 150° F.

Heat yellowed the white samples in both the wool and the rayon groups. The index of fading for "I", white rayon, was 57.44; for "R", white wool, 82.37. From one study (1) it was found that wool seemed to be more susceptible to browning when subjected to heat than were the cellulose fibers. In the same study it was found that cellulose acetate fuses at 200° C. When exposed to heat at a lower temperature, Fletcher and Houston (9) found a decided change in color in all white rayon samples. After 20 hours exposure the viscose changed more than the cellulose acetate.

SUMMARY

This study was made to compare the color fastness of certain wool and of certain rayon gabardines after dry cleaning, and after exposure to light and heat.

Results showed no significant difference between fadings in the colored wools and in the colored rayons, but a very highly significant difference in fading due to treatments.

The colors within fabrics in both the wool and rayon showed a significant difference in indices of fading. Thus, there was considerable variation in the amount of fading for the various colors in both groups of fabrics.

Dry cleaning had little effect on the color in both groups; ten specimens did not fade at all and the others, with the exception of the whites, faded only slightly.

The fading caused by exposure to light was greater than the fading caused by dry cleaning by a very highly significant difference. Only one fabric, the white rayon, did not change color when exposed to light in the Fade-Ometer.

Fading on exposure to heat was greater than that due to dry cleaning by a highly significant difference. There was a significant difference between fadings due to light and those due to heat, the light having caused the greater amount of fading. Three specimens showed no color change after being heated; all three were dark colors, and probably the dye covered any browning that may have taken place in the fabrics.

When exposed to heat, the white wool changed color more than the white rayon, though both were a decided yellow. The white wool also became yellow when exposed to light, but the white rayon showed no color change. Inconclusive results were reached with regard to the effect of dry cleaning on the white samples because the white pieces were cleaned with the colored fabrics.

As far as the color fastness is concerned, these viscose and cellulose acetate rayon mixed gabardines are as satisfactory to use as are the colored wool gabardines. If it is desired that a white fabric retain its whiteness, the rayon is more satisfactory because it does not turn yellow when exposed to light.

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