GERMICIDAL EFFECT OF ULTRA-VIOLET RAYS ON AND THROUGH FABRICS

by

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TABLE OF CONTENTS

INTRODUCTION

Direct sunlight is known to have a marked germicidal action upon most bacteria. Microorganisms are widely distributed in nature and it is to be expected that large numbers will be found on the skin of the human body. Chapin (1910) states that disease producing organisms are carried by clothing. Some other authorities assert that clothing is a protection against infection. Therefore it is of interest to know what factors may be relied upon to govern the choice of clothing in order to protect the human organism against microbial infection. If, through intelligent selection of fabrics for clothing, beneficial light rays are allowed to reach the skin, more organisms will be destroyed and body metabolism will also be benefited.

Elementary experiments have been performed to demonstrate that certain black materials absorb the part of the sun's rays producing heat, but the question arises whether cold rays are also absorbed, and whether the rays, if absorbed, are capable of exerting a germicidal effect on the bacteria.

Little work has been done with fabrics used as filters for ultra-violet rays. Therefore a series of experiments was designed to determine the protective action of certain fabrics using bacteria as an indicator of penetration. The purpose of this investigation was to establish a comparison between cotton, linen, wool, and silk materials as to their relative values as far as penetration of light is concerned.

LITERATURE RELATED TO SUBJECT

The value of sunlight as an aid in preserving health has been recognized for thousands of years, but it was not until Finsen's studies made in the latter part of the nineteenth century that artificial light therapy gained a real stimulus. Today light treatment is used as a specific for rickets, some forms of tuberculosis, and as an aid in curing anemic conditions.

Light is the result of wave motion of the ether, with each color corresponding to a definite wave length. There are waves too short as well as a large percent which are too long to be visible. The energy of the sun is about equally divided between the long rays, and the visible and the ultra-violet region. The ultra-violet region is divided into three parts, the near ultra-violet, or those rays just shorter than the violet rays, middle region, and the far ultra-violet. There are three ways of designating wave lengths:

Angstrom, A	----------	1/10 millionth millimeter
Millimicron, mu	----------	1 millionth millimeter
Micron u,	----------	1 thousandth millimeter

The visible spectrum, including all colors from red to violet, extends from 800 mu to 400 mu. Red has the longest wave length and violet the shortest. The invisible spectrum is made up of infra-red rays which are from 130 u to 800 mu in length, and the ultra-violet rays which lie between 380 mu and 60 mu. Infra-red rays are the heat rays, while the ultra-violet are capable of producing chemical change. The sun's rays contain not only visible light but a certain percent of the near ultra-violet and of infra-red rays. The carbon arc, iron arc, and mercury arc lamps emit light rich in ultra-violet rays.

It has been stated that most substances are increasingly opaque to ultra-violet radiations as the wave length of the radiations decreases (Luckiesh, 1922). Pure water is quite transparent to the near and middle regions. Air transmits no appreciable amount shorter than 170 mu in wave length (Luckiesh, 1922). Finsen demonstrated that ultra-violet rays showed little penetrating power and were absorbed by the blood in the superficial vessels (Mayer,1921). Fluorite and quartz are transparent to ultra-violet and thin layers of gelatine transmit the near and middle regions.

The bactericidal power of light rests chiefly with blue, indigo, violet and ultra-violet rays according to Mayer (1921) and the same author states that the effect on bacteria depends upon the quality and intensity of light, distance of light from the organisms, period of raying, temperature and humidity of air, moist or dry state of the bacteria, age of the culture, species of the organism and its power of movement.

According to Burge, ultra-violet radiation kills living cells and tissues by changing the protoplasm to form an insoluble compound(Luckiesh, 1922). The radiations of the greatest bactericidal power penetrate only a few thousandths of a millimeter (Luckiesh, 1922). Bactericidal action of light is confined to the ultra-violet region of the spectrum beginning at 350 mu and extending with increasing intensity to the shortest wave length measurable with the quartz spectograph or 185 mu. (Bayne-Jones and Van der Lingen, 1922). The spectral range of germicidal action was thought to be different for different organisms, exposed simultaneously. Coblentz and Fulton (1924) have found that the lethal effect for <u>B. coli</u> extended from 296 to 220 mu. The same authors state that Bovie has proved that the action of light is exerted directly upon the organisms and not indirectly through the formation of some toxic substance in the medium. They also state that in order to obtain an estimate of the energy required to kill a bacterium it is necessary to consider the size of the object exposed. Data show that the average length of B. coli is 1.0 to 2.0 u and the width about 0.5 u. The area of a bacterium exposed to radiation is, therefore, about 8×10^{-7} square millimeters.

The Bureau of Standards has published findings on the ultra-violet transmission of fabrics in which they state that after eliminating the light transmitted through openings between threads, transmission coefficients have been deduced for white or uncolored threads as follows:

Cotton varies from 17 to 20 percent
Silk varies from 14 to 18 percent
Wool varies from 5 to 15 percent

The statement is also made that a slight coloring of the fabric greatly decreases the transmission of ultra-violet rays, the penetration through the thread, especially when dyed, being only about 5 to 10 percent. (Technical News Bulletin 1927).

Previous Investigations

Record has been made of a few studies which have a direct bearing on this investigation as far as penetration of light through various fabrics is concerned. Hess and Weinstock (1923) conducted an experiment dealing with the light transmissibility of clothing materials commonly worn by infants. Their results seem to indicate that to be beneficial the rays of the sun do not have to strike the surface of the skin directly. Clothing should be regarded as filter material, similar to glass, the filtering action depending upon its texture and thickness. Black clothing was found to absorb much more of the effective ultra-violet rays than white materials of a similar texture. These fabrics had a like number of threads per square inch and the black were dyed with an anilin dye.

In a study on the protection afforded the skin against sunburn by textile fibers, wool, cotton, linen, and silk fabrics were selected on the basis of weight and thread count per inch, and the problem of absorption of light by color was avoided by choosing white materials. Results show that protection from sunburn depends largely on the percent of interspace in the fabric but that vegetable fibers transmit some of the rays that burn, the coefficient of protection being 3 to 1 for linen, 4 to 1 for cotton, while for wool and silk the ratio is 20 to 1, showing that fewer rays pass through these materials. The same investigation shows that transmission of direct sunlight and rays from the mercury arc lamp gave the same results if the exposure from the latter was reduced ten times (Hess, Justin, and Hamilton, 1927).

Dozier and Morgan (1928) carried on a study of the anti-rachitic potency of irradiated cottonseed oil where clothing materials were used as filters for the rays of the mercury quartz lamp. The oil was fed as part of the diet to rachitic rats. At the end of eight days the McCollum line test was made on the tibial bone of the rats. This showed varying degrees of healing depending upon the time of irradiation of the oil and kind of filters for the ultra-violet rays. They conclude that baby flannel, pongee, and crepe de chine filter out the ultra-violet radiations which are anti-rachitically potent. The small amount of interspace in the baby flannel and the large percentage of ash in the silk materials may have influenced this result. The artificial silk and cotton materials transmit the rays which are effective in healing rickets. These materials had the largest interspace and the smallest percentage of ash. They state that these facts seem to indicate that there are factors other than the fiber which influence transmissibility of ultra-violet radiation through clothing material.

Hoss and Unger (1922) found that when black and white rats were fed the same diet and each given a minimal protective dose of light as prevention against rickets, the rate of growth was the same with both, but the black rats developed rickets while the white ones showed no signs of the disease. This seems to prove that black color absorbs not only heat rays but ultra-violet rays as well.

EXPERIMENTAL

Certain terms should be defined in order to avoid confusion of thought. Penetration is to pierce or to become diffused through. Webster defines black as having little or no power to reflect light or having no spectral color; opposite to white.

Selection of Fabrics

In selecting materials for the experiment those of plain weave were chosen so that the spaces between yarns might be measured and the area not covered by fibers be estimated. White or uncolored fabrics were used because a slight coloring of the fabric greatly decreases the transmission of ultra-violet rays according to Technical News Bulletin (October, 1927). The lightest weight white wool material available in this locality was batiste which was selected to represent wool fiber. The interspaces between both warp and filling yarns were measured for a space of five tenths of a centimeter at three places on the sample. The measurement was made by means of a micrometer microscope. The percent of interspace was determined by dividing the area not covered by yarns by the entire space measured. An average of the three results thus obtained was 14.52 percent and this figure was used as a basis of selection for the cotton, linen, and silk fabrics of similar interspace. The percentage varied between 12.7 percent and the above figure. The materials chosen were cotton sheeting, linen sheeting and silk crepe de chine. Rayon was not included among the fabrics because it was not possible to find an example of all rayon material having a similar percent of interspace as the other four fabrics. Figure 1 shows samples of the four fabrics selected for the experiment.

Fabric Analysis

An analysis of the fabric was then made. It was impossible at the time of year when this was done to gain standard conditions with the apparatus available, but a uniform relative humidity of 30.8 percent was maintained. The dry-bulb thermometer registered 27 ± 1°C. Specimens

Figure 1. Materials Used in Experiment.

for the tests were hung in this atmosphere at least two hours, and tests were made in this room under the above conditions.

As a means of calculating the weight per square yard and the percent of moisture in the fabric a four-inch square was weighed air dry on the analytical balance. The same piece was then dried to constant weight and weighed in the Emerson conditioning oven in which a temperature of 110°C. was maintained.

A thread counter made by Chas. Lowinson Co., New York, was used to determine the picks and ends per inch. An average of three readings was recorded.

The amount and direction of twist of the yarns was determined with a twist counter with the jaws set one inch apart. An average of ten readings was recorded as the number of twists per inch. The direction of twist was determined according to A. S. T. M (1926).

The breaking strength of the fabric, using the strip method, was taken with the Scott Universal Tester for fabrics. This machine had a capacity for 100 pounds. Six inch strips, one and one half inches wide, were raveled down to one inch. Measurement was made by means of a micrometer microscope. The strips were then clamped into the jaws set three inches apart and stretched at the rate of 12 feet per minute until ruptured. A dial registered the breaking strength and the elongation of the strip was measured with a ruler. Three determinations were made for both warp and filling of the fabrics and the average recorded.

To determine the breaking strength of yarns a method similar to that used for serigraphs was devised. Specimens were prepared the same as for breaking strength of fabrics except that for a space of three inches through the middle of the strips the cross-wise yarns were drawn out. These strips were fastened in the jaws of the Scott Universal Tester for Fabrics and stretched until ruptured. The pounds required to break this series of yarns were then divided by the number of yarns making up the inch, and the resulting amount was said to be the breaking strength of a single yarn.

The yarn size of both warp and filling of the cotton, linen, and wool fabrics were determined according to the method suggested by Posselt. For silk, the method described by Cook (1922) was used for the calculations.

The number of fibers found in a cross-section of the various yarns was counted with a microscope and an average of three readings recorded.

The average length of the staple of cotton and wool yarns was determined in the following manner. Single fibers were drawn from untwisted yarns of considerable length and placed parallel. A razor blade was used to cut through this bundle of fibers and both sections were placed, cut end outward, between glass slides and manipulated until the fiber covered a rectangular area with uniform thickness. The length was measured and the result recorded as the average length of staple.

The fabrics were tested for sizing and finishing materials with the result that linen was found to be unweighted, cotton to be weighted with an insoluble substance, (probably china clay), wool had no sizing and silk was found to contain 9.99% soluble weighting, and 1.59% stripped off weighting.

The percent of ash was calculated from the weight of ash left after burning a two-inch square of fabric.

Microscopic examination of the fibers was made to determine the quality of the fiber, and possible adulteration of the fabric.

The results obtained in this analysis are to be found in Table I.

TABLE I A

FABRIC ANALYSIS

Name of Fabric	Cotton Sheeting	Linen Sheeting	Wool Batiste	Crepe de Chine
Fiber	Cotton	Linen	Wool	Silk
Weave	Plain	Plain	Plain	Plain
Color	White	White	White	White
Width of Fabric	108 in.	120 in.	45 in.	39 in.
Price per Yard	$0.39	$2.98	$1.95	$2.50
Bone dry Weight of 4 in. sq.	1.295 gm.	1.293 gm.	.913 gm.	.514 gm.
Breaking Strength				
Warp	46.00 lb.	48.58 lb.	31.66 lb.	36.33 lb.
Filling	36.75 lb.	48.91 lb.	14.58 lb.	34.25 lb.
Breaking Strain per Inch				
Warp	.08 in.	.09 in.	.16 in.	.19 in.
Filling	.23 in.	.13 in.	.19 in.	1.25 in.
Finish of Fabric	Heavily sized	Soft	Soft	Soft
Percent Ash	8.65%	.45%	1.14%	1.42%

Name of Fabric	Cotton Sheeting		Linen Sheeting		Wool Batiste		Crepe de Chine	
Yarn	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
Yarns per inch	61	51	48	45	70	59	123	80
Breaking Strength of Single Yarn	.672 lb.	.520 lb.	.88 lb.	.577lb.	.276lb.	.112lb.	.184lb.	.358lb.
Breaking Strain per Inch	1.38 in.	.159 in.	.125 in.	.125 in.	.166 in.	.125in.	.153in.	.343in.
Twist per Inch	right 18.8	right 20.7	right 11.6	right 11.8	right 15.5	right 15.5	right none	right 61.5
Ply	single	single	single	single	single	single	single	single
Yarn Size	20	22	44	47	40	59	57-59	74-76
Number of Fibers in Yarn	63	54	50	47	76	63	124	84
Length of Staple	.81in.	.75in.	1.08in.	.92in.	2.37in.	1.75in.	Length of piece	Length of piece
Microscopic Nature of Fiber	Cotton	Cotton	Linen	Linen	Merimo Wool	Merimo Wool	Silk	Silk

TABLE IB. YARN AND FIBER IN FABRIC

Dyeing the Fabric

In selecting a color for comparison with that of the material as purchased, black was chosen to secure the greatest possible variation in absorption of light. It was thought necessary to dye the original fabrics in order to standardize results, so that the problem of variation in the size of yarns, picks and ends per inch, twist of yarns, etc. would not enter into the calculation.

An attempt was made to obtain black with the same dye on all the fabrics. A standard commercial dye for mixed goods was used with the result that various blacks were produced. From these results it was decided to use a direct dye for the vegetable fibers, and an acid dye for the animal fibers.

An eighteen inch square of each fabric was dyed. For the vegetable fibers, cotton and linen, "Newport direct black E E" was used in a five percent dyebath with common salt added as a leveling agent; and for the animal fibers, wool and silk, "Newport wool black B" was used in a five percent dyebath with two percent sulphuric acid and twelve and one half percent Glauber's salt.

Comparison of Original and Dyed Fabric

It was then necessary to make a partial analysis of the black fabric so as to determine what changes had resulted from dyeing. The percent of interspace was measured, and to allow for fair comparison with white fabric a sample of each of the new materials was boiled one hour in distilled water, the time required for boiling in the dyebath to produce the color, so that any shrinkage or felting might be accounted for, weighting removed, and differences assigned to their proper causes. Table II gives a comparison of the interspaces of the original material, material boiled one hour, and that dyed black. Boiling seemed to cause a loss of interspace in all materials except silk where we find a 15 percent gain in percent of interspace. Silk was weighted with soluble weighting which was removed in this process. The loss in the other materials was probably due, in part, to the fact that the material was not stretched in ironing to its original state. The shrinkage in cotton was undoubtedly counterbalanced in part by the loss of sizing. Wool lost 25 percent interspace which may be attributed to the shrinking and felting of the material. A comparison of the changes due to boiling and those due to dyeing indicate that the dye bath caused the fiber to disintegrate somewhat except for silk. These

TABLE II

COMPARISON OF PERCENT INTERSPACE IN FABRICS

Fiber	Original Fabric	White Fabric Boiled 1 Hour	Change due to Boiling	Dyed Fabric	Changes due to Dyeing
Cotton	12.98	12.34	5% loss	13.50	4% gain
Linen	12.70	11.30	11% loss	11.56	8% loss
Wool	14.52	10.75	25% loss	11.42	19% loss
Silk	12.87	14.92	15% gain	14.60	13% gain

variations may be due, however, to difference in weight of the fabric in the specimens measured.

The number of picks and ends per inch were counted and compared with the original fabric to determine shrinkage; a four inch square was dried to a constant weight and weighed to estimate the amount of gain in weight due to absorption of dye and shrinkage; and the breaking strength and strain of one inch strips of both the warp and filling of the fabric was taken. A summary of the comparison of the black and white fabrics will be found in Table III.

All of the materials showed a gain in picks and ends per inch, and cotton, wool, and silk lost in the amount of strain they would withstand. Linen remained practically the same. Wool and silk showed considerable loss of strength probably due to the action of the acid dye bath on the fibers.

Permeability of Light Measured

In determining the relation of black and white fabrics to permeability of light it seemed desirable to use a light source which could produce changes rapidly and which was relatively constant. Since the penetration was to be checked against the germicidal action of the light it was necessary that the light source contain rays that were

Fiber	Weight of 4 in. sq.	Ends per Inch	Picks per Inch	Breaking Strength of Warp lbs.	Breaking Strength of Filling lbs.
Cotton					
Original	1.295 gm.	61	51	46	36.75
Dyed	1.336 gm.	65	54	41	26.00
Gain	3.160 %				
Linen					
Original	1.293 gm.	48	45	48.58	50.16
Dyed	1.335 gm.	50	47	48.91	49.00
Gain	3.170 %				
Wool					
Original	.913 gm.	70	59	31.66	14.56
Dyed	1.137 gm.	75	63	25.66	9.33
Gain	24.530 %				
Silk					
Original	.541 gm.	123	81	36.33	34.24
Dyed	.555 gm.	125	84	15.66	13.00
Gain	2.580 %				

TABLE III. EFFECT OF DYEING ON THE VARIOUS FABRICS effective in destroying bacteria. An air cooled quartz mercury arc lamp was therefore used as the source of light in this investigation, and the word light used hereafter may be interpreted to mean ultra-violet rays. The lamp was operated on a direct current line with a relatively constant voltage of 80.

The amount of light penetration through the various fabrics was measured by their ability to screen sensitized paper from the direct rays of the lamp. Half of the sheet of paper was exposed for 20 seconds after the voltage had reached the maximum. This length of time was used because it gave a sufficiently deep color tone on unexposed paper to make possible the matching of color tone with a fair degree of accuracy. This half was then covered and the other half of the sheet, screened by the fabric in motion, was exposed the length of time necessary to develop a tone matching the first half of the paper. Table IV shows the time required for equal penetration through various fabrics.

In each case the sensitized paper was held 18 inches from the quartz tube of the lamp. If the cloth or paper was not in motion a definite impression of the weave of the material was obtained by which an inaccurate idea of color tone was obtained. The light exposed paper was then fixed by treating for ten minutes with a hypo solution made of

TABLE IV

TIME REQUIRED FOR EQUAL LIGHT

PENETRATION THROUGH VARIOUS FABRICS

Fabric	Original Material		Boiled One Hour		Dyed Black	
	Time *:	Ratio	Time	Ratio	Time	Ratio
Cotton	3' 20"	1 - 10	3' 20"	1 - 10	10'	1 - 30
Linen	2' 15"	1 - 6.75	2' 15"	1 -6.75	6' 45"	1 - 20
Wool	3'	1 - 9	4' 30"	1 - 15	13' 30"	1 - 45
Silk	2' 20"	1 - 7	2' 20"	1 - 7	7'	1 - 21

*Time in minutes and seconds required to match 20 seconds direct exposure.

RATIOS SUMMARIZED

Material	Boiled One Hour	Dyed Black	Ratio
Cotton	1 - 10	1 - 30	1 - 3
Linen	1 - 6.75	1 - 20	1 - 3
Wool(Boiled)	1 - 15	1 - 45	1 - 3
Silk	1 - 7	1 - 21	1 - 3

50 grams of sodium thiosulphate and eight ounces of water, and rinsing in running water for 10 minutes. The method used was suggested by Hess, Hamilton, and Justin (1927). Figure 2 shows the color tone developed through the fabrics as compared to the tone brought out by 20 seconds exposure unscreened. Any variation in color of the samples shown may be attributed either to a slight variation in the voltage of the lamp, or to differences that developed in the fixing bath.

A ratio of penetration was then worked out for (1) white fabrics as purchased, (2) white fabrics that had been boiled one hour, this treatment being considered equivalent to that causing shrinking which was used in the process of dyeing, and (3) for the cloth dyed black. This ratio as shown in Table IV was based on the time of exposure required to match the effect on paper of 20 seconds exposure to direct light as compared with the effect when light was screened by the fabrics in question.

An idea of the relation existing between fabrics of similar interspace as to their rate of transmission of light can be shown by index numbers in which linen, the fabric most easily penetrated, was represented by one.

Figure 2a. Sensitized Paper Showing Color Tone Developed by Light Exposure Through Cloth.

Wool

20"	3'	20"	4'30"	20"	13'30"
Original		Boiled 1 Hour		Dyed Black	

Silk

20"	2'20"	20"	2'20"	20"	7'
Original		Boiled 1 Hour		Dyed Black	

Figure 2b. Sensitized Paper Showing Color Tone Developed by Light Exposure Through Cloth.

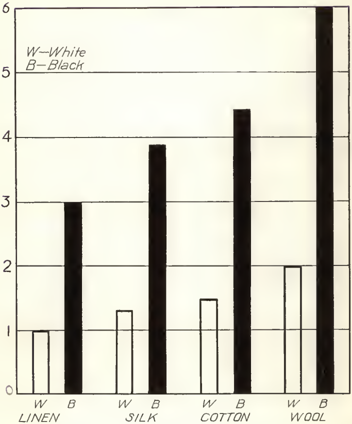

Fig. 3—Relation existing between fabrics as to permeability of light—sensitized paper used as indicator

(See Figure 3).

Linen	1.00
Silk	1.03
Cotton	1.48
Wool	2.00

These differences may be accounted for when the physical characteristics of the fibers are considered. Both wool and cotton yarns are fuzzy and this will tend to fill the interspaces. Linen and silk are smooth yarns.

A relation of one to three was found to exist between all the white and black fabrics if the ratio for wool was calculated on the basis of the boiled wool and dyed wool.

Inoculation of Fabric

For this investigation a pure culture of E. coli was used because it is non-spore bearing and has a resistance to destroying influences about equal to many pathogenic organisms. Coblentz and Fulton (1924) have determined that the range of lethal effect for this organism extends from 296 to 220 mu although it has given evidence of a certain amount of irregularity in its reaction to radiation. They state this may have been due to clumping and to individual differences. A suspension of a 24 hour broth culture was made in distilled water varying in dilution for various phases of the experiment.

Bacteria Washed from Fabrics

In order to determine the effectiveness of ultra-violet rays as a germicide it seemed necessary to know what percent of the organisms placed on a fabric could be washed out. The number on the fabric was estimated on the basis of volume of liquid absorbed. The number of organisms in the suspension was calculated by plating from a series of dilutions with beef extract agar and incubating for 48 hours. A sterile air-dry sample of cloth, six inches square, was weighed in a sterile weighing bottle on an analytical balance. The sample was then dipped in the suspension, freed of all excess liquid by twisting, and re-weighed to determine the weight of the liquid absorbed. It was assumed that the specific gravity of the culture suspension was equal to that of water, or one, and that by multiplying the grams of liquid absorbed by the number of organisms per cubic centimeter the number of organisms in the fabric could be determined.

On washing the cloth in 500 c.c. sterile water, by forcing it through the fabric 100 times, plating out as previously described, and incubating 48 hours before counting,more organisms were removed to the square inch than had been estimated to be present (See Table V). This fact lead to the conclusion that the physical phenomenon, adsorption,

Fabric	White Wool	White Wool	White Cotton	White Cotton
Weight of cloth	2.235 gm.	2.275 gm.	3.350 gm.	3.395 gm.
Weight of culture absorbed	2.375 gm.	2.545 gm.	2.551 gm.	3.630 gm.
Number organisms per c. c. culture dilution	110,000,000	113,000,000	246,000,000	134,000,000
Number organisms absorbed by fabric	261,250,000	287,585,000	627,546,000	486,420,000
Number organisms washed from fabric	750,000,000	1,050,000,000	1,788,350,000	1,168,000,000
Percent washed from fabric	287%	364%	284%	240%

TABLE V. SHOWING PERCENT OF ORGANISMS WASHED FROM FABRICS. BASED ON WEIGHT OF CULTURE ABSORBED might be a factor, and the method just described was considered as unsatisfactory.

According to Bechhold(1919) "adsorption is a phenomenon which is conditioned by the decrease of the surface tension of the solvent in respect to the dissolved substance at the interface between the solvent and adsorbent." He describes the use of silk threads for testing the efficiency of disinfectants. Bacteria were dried on threads, then after dipping in the disinfecting solution, they were placed in bouillon to allow for development of growth. He says that from the standpoint of the colloidal chemist this procedure contains a serious error of method. Knowing that silk is a powerful adsorbent he concludes that silk is not a suitable germ carrier for disinfection experiments since, as the result of adsorption, it retains too much disinfectant and the germ cannot escape.

The following method was then devised for determining the number of organisms in the sample of material. Plates were made from a 1 to 500 dilution of the suspension. A six inch square of sterile fabric was dipped and plates made from the culture a second time. It was estimated that the difference in count per cc between the two readings, times the volume of the suspension, represented the number removed by the material. The sample of cloth was then placed in water of known volume, 500 c.c., and washed under controlled conditions by forcing the water through the fabric 100 times. Sterile rubber gloves were worn to prevent contamination. Plates were made from the wash water to determine the number removed. The number of bacteria per cc in the wash water, times its volume, represented the number washed from the fabric. The length of time consumed in the experiment made it unnecessary to consider the germicidal action of distilled water. By dividing the number washed out by the total number adsorbed, the percent washed out was calculated. Table VI shows the percents washed from white cotton fabrics. The figures varied widely and proved to be such a small percent in some cases that the percent of error might equal the percent washed out. Table VII is a summary for the four white fabrics. No tests were made with black fabrics.

Light as a Germicide

Although conditions of working were controlled as much as possible there were factors which made the quantitative method seem undesirable and an experiment was planned in which the number of organisms washed from an unexposed and an irradiated piece of cloth were compared.

Kind of Fabric	Organisms per cc in 500 cc culture suspension	Organisms per cc After fabric has been put through suspension	Organisms held in 6 in. sq. of fabric	Organisms in wash water	Percent Organisms Washed Out
White Cotton					
A	680,000	520,000	80,000,000	6,500,000	8.12%
B	82,466	62,850	9,808,000	995,000	10.10%
C	37,033	31,166	2,933,500	460,000	15.61%
D	81,750	70,000	5,875,000	940,000	16.20%
E	36,500	32,566	1,967,000	383,500	19.40%
F	2,460,000	2,055,000	202,500,000	44,175,000	21.8%
G	1,293,000	1,184,000	54,500,000	15,800,000	28.9%
H	116,000	90,500	12,750,000	2,270,000	18.9%
I	47,733	41,433	3,150,000	957,500	30.3%
J	105,500	90,500	7,500,000	1,730,000	23.0%
K	34,833	32,466	1,183,500	373,500	31.5%
L	37,233	32,300	2,466,500	616,000	24.9%
AVERAGE	417,695	353,566	32,054,417	6,266,708	19.5%

TABLE VI. SHOWING THE METHOD OF DETERMINING PERCENT BACTERIA WASHED FROM SIX INCH SQUARE COTTON FABRIC

TABLE VII

SHOWING THE PERCENT BACTERIA WASHED FROM THE

VARIOUS FABRICS IN ONE WASHING

White Cotton	White Linen	White Wool	White Silk
%	%	%	%
8.12	5.6	6.5	7.9
10.10	12.9	10.9	24.9
15.61	12.3	24.1	17.4
16.2	47.7	13.6	10.3
19.4	36.8	26.0	17.8
21.8	43.0	22.5	23.0
28.9	18.4	10.9	16.6
18.9	26.0	9.0	19.4
30.3	38.6	10.5	7.7
23.0	39.3	9.2	10.9
31.5		10.0	
24.9		6.5	
AVE. 20.7	28.0	13.3	15.5

On Inoculated Fabrics. A strip of fabric two inches by five inches was marked off in one inch squares by drawing threads. The piece was then sterilized, dipped into a one to ten dilution of 24 hour broth culture of E. coli, excess moisture pressed out, and the sample cut with sterilized scissors into one inch squares. Alternate pieces were placed directly into 99 cc water blanks and the others into a sterile Petri dish for exposure to direct ultra-violet light for ten minutes. These samples were irradiated on one side, at a distance of 18 inches from the quartz tube. Each of these samples was then placed in a dilution blank. Washing was accomplished by shaking each blank 100 times and again 50 times just before plating from a series of dilutions. The plates were allowed to incubate 48 hours before counting. The effectiveness of light as a germicidal agent represents the percent bacteria destroyed. This was determined by dividing the number of bacteria per square inch of fabric remaining after exposure by the number present on the unexposed fabric. This gives the percent remaining. By subtracting the last named figure from 100, the percent destroyed is obtained. Table VIII shows the detailed method of arriving at these results. An average of five readings obtained from specimens run at the same time is represented in each record of "percent destroyed."

TABLE VIII

EFFECTIVENESS OF IRRADIATION IN DESTROYING BACTERIA - DETERMINED BY WASHING OUT ORGANISMS HELD IN THE FABRIC

Name of Material	Bacteria removed from 1 sq. in. fabric before exposure	Removed from 1 sq. in. fabric after exposure	Effectiveness of Irradiation
White Wool	2,880,000	1,649,000	
	2,900,000	2,400,000	
	2,870,000	1,870,000	
	3,740,000	1,650,000	
	4,275,000	1,390,000	
AVERAGE	3,540,000	1,791,800	49.38%
White Wool	1,705,000	14,000	
	2,320,000	18,000	
	2,155,000	27,000	
	1,980,000	14,000	
	2,015,000	18,000	
AVERAGE	2,235,000	18,200	99.2%
White Wool	4,270,000	110,000	
	3,710,000	122,000	
	3,961,000	119,000	
	4,100,000	100,500	
	3,784,000	73,500	
AVERAGE	3,965,000	105,000	97.4%
		FINAL AVERAGE	81.72%

Table IX gives a comparison of all the materials and represents an average of ten readings for white fabrics except white wool, where there are fifteen, and an average of fifteen for black. The white materials cotton, linen, and silk show ten minutes exposure to be 99.9+ percent effective as a germicidal agent; for wool the percent is smaller. Black fabrics offer greater protection for bacteria than the corresponding white material, but results vary so widely that more tests should be made before further conclusions may be drawn. The nature of the dye may be a factor in explaining the wide differences between the effectiveness of light on bacteria held by the animal and vegetable fibers.

Fabrics Used as a Screen. The screening effect of the various fabrics was checked with their ability to protect bacteria in a distilled water suspension. Five cc of a 1 to 10 dilution of a 24 hour broth culture of E.coli was placed in a sterile Petri dish. A screen of a sterile piece of the fabric, held at a definite tension in a wooden frame, was used to cover the open plate. To allow for equal exposure to light and facilitate penetration through the depth of the suspension the plate was rotated. Accurate check on the time was kept with a stop watch. Dilutions were made from the irradiated culture suspension, plated out, and the plates incubated 48 hours before counting.

TABLE IX

PERCENT EFFECTIVENESS OF IRRADIATION IN

DESTROYING BACTERIA ON VARIOUS WHITE AND BLACK FABRICS

Fabric		White		Black
		%		%
Cotton		99.98		57.30
		100.00		32.5
				5.66
	Average	99.99	Average	31.82
Linen		99.997		9.8
		100.00		7.4
				31.03
	Average	99.998	Average	16.07
Wool		97.40		81.5
		99.20		94.1
		49.38		51.8
	Average	81.99	Average	75.8
Silk		99.99		99.92
		99.88		86.10
		99.99		99.93
				94.5
	Average	99.95	Average	95.11

Two sets of readings were taken with this method; one with a uniform time of exposure of five minutes; the other with the time varied according to the ratios established as determined by the use of sensitized paper.

Table X is a summary of the results gained from plate counts, and shows the effectiveness of ultra-violet rays through fabrics when the time of exposure is uniform. The percents represent the number of bacteria remaining as compared to the original culture. Direct exposure is 99.99+ percent effective in freeing the suspension of living organisms. Results show that the silk fabric transmits a larger portion of the effective rays than the other fabrics; linen is second. Although the results are not consistent in every case they seem to be significant in that each group of black and white fabrics of the same fiber holds a similar relation to each other as the others in that class. Arranged in tabular form a summary of the results show the black and white fabrics to hold the following relation when exposure to light was five minutes (see Figure 4):

	White	Black
Cotton	1	1.59
Linen	1	4.07
Wool	1	1.18
Silk	1	8.14

Original Culture	Direct Exposure	Cotton		Linen		Wool		Silk	
		White	Black	White	Black	White	Black	White	Black
%	%	%	%	%	%	%	%	%	%
100	.0003	29.0	49.0	6.0	23.6	28.6	32.5	0.5	3.4
100	.0002	43.5	66.3	9.9	35.2	40.6	41.1	1.9	22.0
100	.0003	30.6	47.1	5.4	37.2	38.2	42.4	1.6	18.8
100	.0003	33.3	46.4	13.8	23.8	23.8	34.1	4.9	27.6
100	.0007	32.2	50.3	4.2	16.1	39.6	42.2	2.0	18.9
100	.0020	30.5	57.1	6.0	41.8	43.3	54.8	2.3	25.4
100	.0006	31.1	49.5	7.1	28.5	34.7	41.2	2.26	16.4

TABLE X. SHOWING EFFECTIVENESS OF FIVE MINUTE EXPOSURE TO ULTRA-VIOLET RAYS IN DESTROYING BACTERIA WITH FABRICS USED AS SCREEN. (PERCENTS REPRESENT NUMBER OF BACTERIA REMAINING AFTER EXPOSURE)

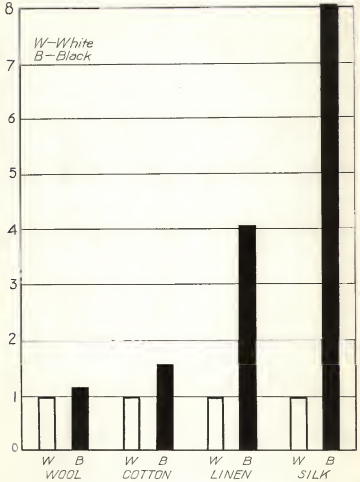

FIG. 4.—Relative germicidal effect of ultra-violet rays through fabrics used as a screen. Time of exposure constant–5 minutes, black proving less effective than white

If bacteria are killed by the same amount and kind of light rays as those developing color tone on sensitized paper it seems evident that a ratio of 1 to 3 should exist in each case rather than those just listed. It may be that the dye is capable of absorbing some of the rays exerting a lethal effect on E. coli, or the difference may be due to the physical properties of the various fibers and yarns, or to other causes not considered.

Luckiesh (1922) compares the bactericidal action of ultra-violet light with the chemical action of ultra-violet rays. He states that rays passing through a viscouous screen have 300 times as much bactericidal power as those through glass, but only 1.6 to 5 times greater chemical action. Also that radiation passing through a quartz screen was 1,000 times greater than the standard, but the chemical action was only four to six times greater. This may be an explanation of the fact that light penetration as indicated by sensitized paper and germicidal action on a culture suspension do not maintain the same ratios.

When the time varied according to the ratios established for light penetration, five minutes exposure was used for white linen, or the material showing the greatest amount of light transmission. The time of exposure for the other materials was worked out by proportion on this basis.

Original Culture	Direct Exposure	Cotton		Linen		Wool		Silk	
		White	Black	White	Black	White	Black	White	Black
%	%	%	%	%	%	%	%	%	%
100	.0008	42.6	27.5	33.7	4.8	10.5	.5	13.6	.03
100	.0000	1.05	0.55	.83	.008	6.59	.18	3.66	.01
100	.0000	35.13	.01	22.19	.79	13.92	.14	.18	.01
100	.001	16.32	.55	.52	.01	.55	.30	.74	.19
100	.0000	1.75	.008	1.11	.11	.27	.05	2.06	.01
100	.0000	30.10	.12	12.09	.04	3.33	.26	1.51	.05
100	.0003	21.16	4.79	11.74	.95	5.82	.24	3.62	.03

TABLE XI. SHOWING EFFECTIVENESS OF EXPOSURE TO ULTRA-VIOLET RAYS IN DESTROYING BACTERIA WITH FABRICS USED AS A SCREEN WHEN THE TIME WAS VARIED ACCORDING TO RATIOS. (PERCENTS REPRESENT NUMBER OF BACTERIA REMAINING AFTER EXPOSURE)

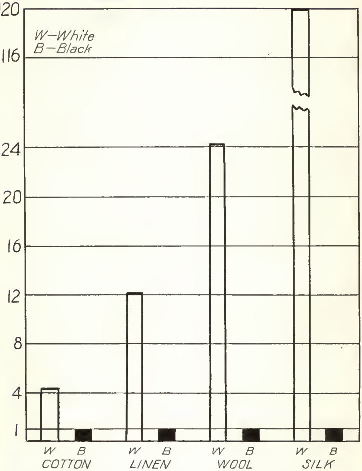

FIG. 5.—Fabrics used as a screen for ultra-violet rays. Time varied according to ratios of penetration established with sensitized paper, irradiation through black fabric proving more effective than through white

If bacteria were killed by the rays causing sensitized paper to be affected, light would have proved equally effective for all fabrics. The germicidal action of light through black fabrics is, according to the data presented in Table XI, more effective than that through white fabrics. Figure 5 summarizes the results and shows relations existing between black and white fabrics. This result may be accounted for by the fact that black fabrics received three times as long irradiation as the white, and tends to prove that most of the light rays effective in destroying bacteria pass through the interspace of fabrics.

SUMMARY AND CONCLUSIONS

Results obtained from the preceding experiments tend to establish the following facts:

1. Bacteria are held in a fabric by some physical force which makes difficult the removal of a large percent of those placed on the material by the mechanical process of washing.

2. A ten minute exposure to ultra-violet rays is more effective in its germicidal action to organisms on white cotton, linen and silk fabric than to those on wool having a similar percent interspace.

3. Ultra-violet light is less effective in its

germicidal action to organisms exposed on black than on white material, but more tests should be made before conclusions as to the relation between fabrics may be drawn.

4. When the fabric is used merely as a screen for light rays and the time of exposure is uniform, black offers more protection for bacteria than white material of similar interspace. Light seems to be more effective in destroying bacteria through silk and linen materials than through those of cotton and wool.

5. When the length of time of exposure varied and the bacteria screened by black fabrics were given three times as long irradiation as those screened by the white, light through the black fabrics was more effective than through white material. This tends to establish the fact that the size of interspace is of greater importance in transmitting ultra-violet rays of germicidal power than is the color of the fabric.

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LITERATURE CITED

1. Bayne - Jones, S. and Van der Lingen, J. S.
   1922. Bactericidal Action of Ultra-violet Light. Johns Hopkins Hosp. Bul. 34: 11-16.

2. Bechhold, Prof. H.
   1919. Colloids in Biology and Medicine. D. Van Nostrand Co., N. Y. p. 25 and 405.

3. Coblentz, W. W. and Fulton, H. R.
   1924. A Radiometric Investigation of the Germicidal Action of Ultra-violet Radiation. Sci. Papers of Bur. of Standards. Vol. 19, No. 495, p. 647, 644, 677.

4. Cook, A. A.
   1922. Tin Weighting in Silk. Textile World. 61: 131-133.

5. Dozier, Carrie C., and Morgan, Harriet.
   1928. Penetration of Ultra-violet Rays Through Clothing Materials. Am. Jour. Physiol. 84: 603-609.

6. Hess,Katherine, Hamilton, J. O. and Justin, Margaret.
   1927. Protection Afforded the Skin Against Sunburn. Jour. Agri. Research. 35: 253.

7. Hess, Alfred F., M.D., and Unger, Lester.
   1922. Newer Aspects of the Rickets Problem. J.A.M.A., 78:1177-1183.

8. Hess, Alfred F., M.D., and Weinstock, Mildred.
   1923. A Study of Light Waves in Their Relation to Rickets. J.A.M.A. 80:689.

9. Luckiesh, M.
   1922. Ultra-violet Radiation. D. Van Nostrand Co., N. Y. p. 35, 38, 208, 214.

10. Mayer, Edgar.
    1921. Sunlight and Artificial Light Therapy in Tuberculosis. Am. Rev. of Tuberculosis. Vol. 5, No. 2, April1921. p. 85, 99.

BIBLIOGRAPHY

Bayne-Jones, S. and Van der Lingen, J. S.

1922. Bactericidal Action of Ultra-violet Light. Johns Hopkins Hosp. Bul. 34:11-16.

Bechhold, Prof. H.

1919. Colloids in Biology and Medicine. D. Van Nostrand Co., New York.

Bowles, Robert L.

1893. Influence of Solar Rays on the Skin. British Jour. of Dermatology (Reprint) Vol.3 Jan. and Dec. 1893.

Buchanan, Estelle D., and Buchanan, R. E.

1914. Household Bacteriology. MacMillan Co., N. Y.

Burge, W. E.

1915. Mode of Action of Ultra-violet Radiation in Injuring Living Cells. Am. Jour. Physiol. 39:335-344.

Chapin, C. V.

1910. Sources and Modes of Infection. J. Wiley & Sons, N. Y.

Coblentz, W. W., and Fulton, H. R.

1924. A Radiometric Investigation of the Germicidal Action of Ultra-violet Radiation. Scientific Papers of Bureau of Standards. Vol. 19, No. 495.

Committee D-13 on Textile Materials

1925. A. S. T. M. Specifications and Methods of Test for Textile Materials. American Society for Testing Materials. Philadelphia.

Cook, A. A.

1922. Tin Weighting in Silk. Textile World. 61:131-133.

Cravath, J. R., and Lansingh, Van Renselaer

1907. Practical Illumination. McGraw-Hill Book Co., N. Y.

Dozier, Carrie C., and Morgan, Harriet.

1928. Penetration of Ultra-violet Rays Through Clothing Materials. Am. Jour. Physiol. 84:603-609.

Gutherie, David Vance.

1917. Electromagnetic Theory of Light. Sci. Monthly. 4:120-131.

Herzfeld, Dr. J.

1920. The Technical Testing of Yarns and Textile Fabrics. Scott, Greenwood and Son, London.

Hess, Katherine, Hamilton, J. O., and Justin, Margaret.

1927. Protection Afforded the Skin Against Sunburn. Jour. Agri. Research. 35:251-259.

Hess, Alfred F., M.D., and Unger, Lester.

1922. Newer Aspects of the Rickets Problem. J. A. M. A. 78:1177-1183.

Hess, Alfred F.,M.D., and Weinstock, Mildred.

1923. A Study of Light Waves in Their Relation to Rickets. J. A. M. A. 80:687-690.

Kimball, Arthur L.

1923. A College Text-book of Physics. Third Edition. Henry Holt & Co., New York.

Kudobe, Esther.

1927. The Extent of Deterioration of Woolens as Caused by Bacterial Action. Thesis. Iowa State College.

Luckiesh, M.

1922. Ultra-violet in Sunlight. Scientific American. 127:258.

Luckiesh, M.

1922. Ultra-violet Radiation. D. Van Nostrand Co., N. Y.

Luckiesh, M. and Pacini, A.

1926. Light and Health. Williams and Wilkins, Baltimore, Md.

Mayer, Edgar,M.D.

1926. Clinical Application of Sunlight and Artificial Radiation. Williams and Wilkins Co., Baltimore, Md.

Mayer, Edgar.

1921. Sunlight and Artificial Light Therapy in Tuberculosis. Am. Rev. of Tuberculosis (Reprint) Vol. 5. No. 2, April 1921.

Posselt, E. A.

Third Printing. Textile Calculations. Bragdon Lord and Co., N. Y.

Schanz, F.

1919. Effect of Light on Living Organisms. Sci. Am. Sup. 88:179.

Ultra-violet Light and Vital Processes. Science n.s.(sup)

1925. 61:10-12.

Ultra-violet Transmission of Fabrics. Technical News Bul.

1927. Bureau of Standards. October.

Winegar, Gladys.

1928. A Study of the Bacterial Content of Cotton Undershirts. Jour. of H. E. 20:349-354.

Woodruff, Chas. E.,M.D.

1909. Case Against the Sun. K. C. Medical Index Lancet. Vol. 32, July, 1909.