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Tim Padfield and Sheila Landi

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There is no very effective way of reducing the rate of fading. Ultraviolet absorbers over light sources give a worthwhile increase in light-fastness to most, but not all, dyes. Low relative humidity reduces fading. Display in cases filled with an 'inert' gas benefits most dyes but accelerates the fading of some pigments used on fabrics. Valuable textiles whose dyes have a light-fastness below 6 should not be permanently displayed.

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The Light-fastness of the Natural Dyes

'Vegetable dyes *mellow*, modern ones tend to *fade*.'
(quoted in *The Times*, Sept. 7, 1966)

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ABSTRACT

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Nearly all natural dyes have a light-fastness below BS grade 5. Most have a fastness below 4. Nearly all natural dyes will fade badly during an exposure to 50 million lux hours of artificial light, or to a much smaller dose of daylight. In many museum displays serious fading of most dyes would occur in less than fifty years.

There is no very effective way of reducing the rate of fading. Ultraviolet absorbers over light sources give a worthwhile increase in light-fastness to most, but not all, dyes. Low relative humidity reduces fading. Display in cases filled with an 'inert' gas benefits most dyes but accelerates the fading of some pigments used on fabrics. Valuable textiles whose dyes have a light-fastness below 6 should not be permanently displayed.

INTRODUCTION

Nearly all the natural dyes are obsolete and accurate fastness data are scanty. These dyes still form the greater and more valued part of the dyes in museum textile collections. We have tried to find out how quickly some of the commonest of them can be expected to fade in daylight and in fluorescent lamp light.

METHODS OF TESTING LIGHT-FASTNESS

The first systematic tests of the light-fastness of dyes were made by Dufay [1] about 1733. The novelty of his method was that it prevented the inconstancy of daylight from affecting the results of tests made at different times and places. He used as the unit of exposure the time taken for a standard dyeing to fade to a specified colour. This standard was always exposed beside the specimen under test. These fading experiments were part of an attempt to develop a system of chemical tests which would rapidly distinguish between dyes of high and low light-fastness and eliminate the tedious business of exposing them. The futility of this approach is now apparent, but although the chemical experiments are recorded we can find no trace of the results of exposure.

All subsequent methods of any accuracy have used some device to eliminate the variability of daylight. Unfortunately many published data are based on less careful techniques.

In the British Standard (BS) method [2] the dyed cloth is exposed behind glass to daylight. The test specimens face south and are held at an angle to the horizontal equal to the latitude. The rate of fading of the specimens is assessed by comparison with the fading of a set of standard dyeings which are exposed at the same time. These are eight pieces of blue-dyed wool. They are numbered and the dyes have

been chosen so that standard 1 fades about twice as fast as standard 2, which fades about twice as fast as standard 3 and so on. Dyes are classed with the number of the standard which fades at the same rate. The approximate daylight energy needed to fade the standards is given in Table 1. Other national standards are based on the same principle. The test of the International Standards Organization is substantially the same as the BS test.

Safflower: Completely fades in air in 20 days. In water vapour only cotton dyeings last longer. In vacuo there is only very slight fading in 2 years.

Orchil: Fades in 20 days. In water vapour only fades on cotton. In vacuo it fades slowly on cotton, becomes bluer on silk and wool.

Indigo: Fades in 15 days on cotton. Fades much more slowly on silk and wool but fading is noticeable in 75 days. Stable in vacuo on all fibres.

Sulphonated Indigo: Fades in 10 days on wool and 80 days on cotton but on silk it is still fairly blue after 2 years. In vacuo dyed cotton and wool fade rapidly (30 days) but silk retains its colour after two years.

Prussian Blue: Becomes greener on exposure but fades little in two years. In vacuo it fades within three days on all fibres. In water vapour destruction is even more rapid.

TABLE I

Solar radiation in langleys (cal/cm²) required to fade the BS dyed cloths. Based on the data of Rawland [3]. *Other authors give considerably different values* [4]. *One langley is very approximately equivalent to* 1200 *lux hours* [5]. *The GS definition of fading is described in the text and shown, approximately, in Fig.* 1.

Standard	1	2	3	4	5	6
First perceptible fade	37	82	190	350	1 500	5 400 langleys
GS 4	190	650	1 200	2 400	7 200	10 000
3	650	1 200	2 500	4 900	16 000	24 000
2	1 200	2 500	5 600	8 400	24 000	100 000
1	2 500	4 900	8 400	32 000	160 000	

PREVIOUS TESTS ON NATURAL DYES

Several tests of the light-fastness of natural dyes have been published. Senebier [6] exposed to sunlight a number of dyes on silk ribbon. He did not identify the dyes but observed that some of them faded in four or five minutes. Chevreul [7] tested the light-fastness of some natural dyes and a pigment in various atmospheres. His results are summarized below:—

Dyed cotton, silk and wool exposed behind two layers of glass to south daylight in Paris.

Turmeric: Fades in air within 7 days. In a vacuum it fades in 15 days.

Annatto: Initially reddens in light but on cotton and silk it is much faded after 18 days. On wool it is less permanent and fades in 11 days. Absolutely permanent in vacuo on cotton and silk but on wool it fades in 60 days. In water vapour Annatto fades on cotton, silk and wool.

Crookes [8] quoted some results obtained by Kallab in 1872. Many dyes faded within three to eight days and only Madder survived three months' exposure without fading.

Köhler [9] tested the light-fastness of many vegetable dyes on wool. He used the German standard method which, although very similar to the BS method, generally gives a light-fastness rating $\frac{1}{2}$ to 1 unit higher. Of the forty specimens tested only eight had a fastness of 5 or above. Dyes of fastness below 5 will fade noticeably during about five years of exposure in a museum showcase.

Strömberg [10] also stressed the poor light-resistance of natural dyes but gave no detailed

results. We are surprised by her claim that dark yellow cellophane afforded no protection to the dyes. In our experiments an orange filter very much reduced the fading of every dye.

THE BRITISH ASSOCIATION REPORT

The most comprehensive tests of the light-fastness of natural dyes were made between 1890 and 1899 by a committee appointed by the British Association for the Advancement of Science [11]. Their method differed from that used now. There was only one standard. When this had faded by a predetermined amount it was replaced by a fresh pattern of the same material. The quantity of incident light thus defined was named the standard fading period (SFP). Dyes of which only a faint trace remained after one SFP were put in class I. Dyes which showed very marked fading after two SFP were put in class II. The dyes of class III showed distinct fading after two SFP, more pronounced after three. Class IV dyes retained a pale shade after seven SFP, showing little fading during periods one, two and three. Class V dyes were little faded after about one year of exposure (eleven SFP) to daylight at Adel, at that time a village north of Leeds.

This method of assessing the light-fastness had a flaw: a phrase such as 'marked fading' applied to a dye after a month's exposure could equally well describe its state after six months (see Table I).

Because of this vagueness of definition the only way of correlating the BA and the BS methods is to compare the BA fastness with the BS rating of those dyes which have been tested by both methods. The results are shown in Table II.

It is interesting to note that the repeated exposure of a single standard (Blue Wool Standard no. 7) is now the recommended procedure for assessing the light-fastness of dyes and pigments of fastness greater than 8. The method of Dufay and of the BA Committee has returned to favour!

FADING IN ARTIFICIAL LIGHT

Many textiles in museums are exposed only to artificial light. The effect of fluorescent lamp light on sensitive materials has been the subject of a number of articles, but no natural dyes have been exposed.

Feller [12] tested the fastness of a few lake pigments under fluorescent lamps. Alizarin Lake showed a fastness of 4-5, and Quercitron Lake 2-3. Saffron and Carmine (Alkanet?) pigments showed an even lower light fastness.

We have exposed a number of natural dyes and fabric pigments, together with the standards, under two types of fluorescent lamp. Filters have been used to separate the effects of different wavelengths.

The BS coloured wools are intended to govern daylight exposure and do not fade at the same relative rates in artificial light. It is therefore misleading to give dyes a BS rating based on exposure under fluorescent lamps. We have assessed the light-fastness of dyes by reference to the standard grey scale (GS) [13] and calculated the light exposure from measurements of time and illumination. The results of these experiments are summarized in Tables III and IV.

The GS number defines the contrast between two coloured areas. Some dyes darken or change in hue during exposure. Fig. 1 gives some idea of the relation between the GS number and the extent of fading. The reader must bear in mind that the photographic reproduction is not perfect.

DISCUSSION OF THE RESULTS

Most of the dyes tested faded rapidly and their fastness is very low by modern standards. Few of the dyeings had a fastness much greater than that of standard 4.

Among the brightly coloured or pale dyeings only those of Cochineal, Indigo, Prussian Blue, Madder and related dyes showed adequate light-fastness by modern standards. With the exception of Indigo all

TABLE II

The fading in daylight of natural dyes on wool

BA fastness grading	I	II	III	IV	V
Approx. BS grading	1	1–2	3	4–5	5–7
Approx. light exposure to cause GS contrast 3 (million lux hours)	0·5	1	2·5	6	25—
Red dyes	Orchil Barwood (Al) Sanderswood (Al)	Limawood (Al) (Sn) Barwood (Sn)[1] Sanderswood (Sn) Camwood (Al) (Sn)[1] Ventilago (Al) (Sn)	Cochineal (Al) Kermes (Al)	Lac dye (Al) Munjeet (Al)	Cochineal (Sn) Kermes (Sn) Lac dye (Sn) Madder (Al) Turkey Red Chay Root (Al)[3] Morinda (Al) (Sn) Mang Kudu (Al) (Sn)
Orange and yellow	Young Fustic (Al) Kamala (Silk) Annatto Saffron Turmeric Tesu (Al) Gardenia Coscinium Evodia	Young Fustic (Sn) Kamala (Al) Jack Wood (Al) (Sn) Old Fustic (Al) (Sn)[2] Quercitron (Al) (Sn)[2] Tesu (Sn) Persian Berries (Al) (Sn)	Weld (Al) Morinda	Weld (Sn)	Munjeet (Sn) Morinda (Sn) Sophora (Sn) Madder (Sn) Chay Root (Sn)
Blue		Logwood (Al)			Indigo Prussian Blue
Green	Lo Kav (cotton)				
Brown		Limawood (Cu)	Sanderswood (Cu) (Fe) Ventilago (Cu) (Fe) Camwood (Cu) (Fe) Barwood (Cu) (Fe)		Cochineal (Cu) (Fe) Morinda (Cu) (Fe) Mang Kudu (Cu) (Fe) Chay Root (Cu (Fe) Munjeet (Cu) (Fe) Madder (Cu) (Fe) Lac dye (Cu) (Fe)
Black		Limawood (Fe)	Logwood (Fe) Cochineal (Fe)		
Violet		Logwood (Sn)			

Notes.—1. Turns brown and darker, then fades. 2. Changes rapidly during the first exposure period to an olive yellow which is moderately fast. 3. 'The superior colour fastness of the red given by Chay root as compared with Madder is no doubt due to the absence of purpurin in the former'.

TABLE III

The fading of dyes under Philips K 34 fluorescent lamps

Dye, mordant and fibre	Depth of Shade‡	Exposure, in million lux hours 6·5	23	36	36*	36†	Remarks
		Grey Scale Contrast					
Standard 1		2·0	1·3	1·0	1·0	1·5	
2		2·5	1·7	1·3	1·7	2·6	
3		3·5	2·4	1·5	2·4	3·6	
4		4·6	3·7	3·1	4·0	4·6	
5		5	4·5	4·0	5	5	
Brazilwood (Al) wool	1/2	2·7	1·8	1·3	1·7	3·6	Brazilwood on wool is somewhat protected by the u.v. filter. On cotton it is not.
Brazilwood treated with NH_3	1/1	3·3	2·3	1·9	2·4	4·1	
Brazilwood (Al) cotton	1/1	3·5	2·7	2·3	2·3	3·7	
Cochineal (Al) wool	2/1	4·8	4·5	4·1	4·4	4·9	Turns bluer and darkens before fading.
(Sn) wool	1/1	4·9	4·5	4·1	3·7	4·3	
Madder (Al) wool	2/1	3·9	3·7	3·4	4·1	4·6	
(Al) cotton	1/1	4·7	4·7	4·9	4·7	4·9	
(Sn) wool	1/1	3·9	3·3	2·8	3·0	4·0	
(Fe) wool	1/1	4·6	4·2	4·3	5	4·5	
Logwood (Fe) wool	1/1	4·5	4·2	3·8	4·4	4·8	
(Sn) wool	2/1	4·0	3·2	2·5	3·4	4·5	Fades browner
Cutch (Al) cotton	1/1	4·5	3·5	2·6	2·9	4·9	
(Fe) cotton	1/1	4·6	3·7	3·2	3·6	4·9	
Indigo cotton	1/1	4·3	3·8	3·7	4·0	4·3	Indigo is much faster on wool than on cotton.
wool	2/1	5	4·9	4·9	4·9	4·9	
Quercitron (Al) wool	2/1	4·2	3·6	2·8	3·6	4·8	Darkens before fading
(Al) cotton	1/1	4·4	4·4	4·6	4·6	4·7	
Turmeric (Al) wool	2/1	1·3	1·0	1·0	1·0	4·5	Very fugitive but well preserved in orange light.
Weld (Al) wool	1/1	4·3	4·0	3·2	3·5	4·9	
Persian Berries (Al) wool	2/1	4·8	4·4	4·3	3·7	4·5	

* Wavelengths less than 4000 Å absorbed by u.v. filter over patterns.
† Wavelengths less than 5550 Å absorbed by orange filter over patterns.
‡ The figures in this column give the depth of dyeing according to BS 2661: 1956. Depth of shade is determined by reference to a standard catalogue of shades.

TABLE IV

The fading of dyes under Atlas 'Northlight' fluorescent tubes

Dye	Mordant	Fibre	Colour	Depth	Exposure, million lux hours 7·8	36	91	Remarks
					Grey	Scale	contrast	
Quercitron	Al	c	yellow	1/1	4·7	3·8	2·3	
	Al	w	yellow	2/1	4·1	2·7	1·5	reddens before fading
	Sn	w	orange	2/1	3·8	2·9	1·4	
	Cr	w	brown	1/3	4·8	3·3	1·9	
Flavin	Sn	w	orange	1/1	3·2	2·2	1·0	becomes browner before fading
	Sn	w	brown	2/1	3·7	3·5	2·0	
Turmeric	—	w	yellow	2/1	2·0	1·0	<1	
Weld	Al	w	yellow	1/1	4·4	3·2	2·0	the fastest of the bright yellow natural dyes
Chrome Yellow	—	c	orange yellow	1/1	3·8	3·4	2·5	turns browner before fading
Iron oxide	—	w	pale brown	1/3	3·9	2·8	2·0	darkens in light
	—	c	pale brown	1/25	4·9	4·5	2·8	
	—	s	grey brown	1/25	3·4	2·3	1·6	
Fustic	Fe	c	grey	1/1	4·8	3·5	2·3	
	Al	c	yellow grey	1/3	2·9	1·9	1·0	fades pinker
	Al	w	yellow	1/1	3·1	2·8	2·1	turns brown before fading
	Al	s	dull yellow	2/1	4·4	3·1	1·9	darkens then fades to pale pink
Persian Berries	Cu	s	pale yellow green	1/3	4·4	3·8	2·9	fades to pale pink
	Cu	w	dull green	1/3	5	4·6	4·0	
	Cu	w	brown	1/1	5	4·8	4·3	
	Sn	w	dull orange	1/1	4·5	4·4	3·9	darkens before fading
Cutch	Al	c	brown	1/1	4·0	2·4	1·6	
	Cr	c	dark brown	1/1	3·6	2·1	1·3	fades greener
	Fe	w	dark brown	1/1	4·7	3·4	2·2	
Brazilwood	Sn	s	pale pink	1/25	3·2	1·9	1·2	
	Al	s	pink	1/3	2·7	1·3	<1	Brazilwood fades very rapidly. It was reputedly used to brighten Madder
	Al	c	crimson	1/1	3·0	1·9	1·2	
	Sn	w	red brown	1/1	3·5	1·8	<1	
	Cu	w	dark brown	1/2	4·2	2·8	1·7	
	Al	w	pink	1/1	2·6	1·6	<1	
	Al(+NH_3)	w	magenta	1/1	3·7	2·2	1·0	
	Fe	w	red brown	1/1	3·7	2·0	1·0	
Madder	Al	s	pale pink	1/3	5	3·6	2·2	
	Al	w	dark red	2/1	3·7	1·8	1·0	
	Al	c	pink	1/1	5	4·1	3·0	
	Sn	w	red	1/1	4·3	3·4	2·4	
	Fe	w	brown	1/1	4·9	4·4	3·4	

Dye	Mordant	Fibre	Colour	Depth	Exposure, million lux hours 7·8	36	91	Remarks
					Grey	Scale	contrast	
Cochineal	Al	w	crimson	2/1	5	4·5	3·3	darkens, fades bluer
	Sn	w	crimson	2/1	4·5	3·7	3·4	
	Al	s	magenta	2/1	4·7	2·7	1·6	
	Fe	c	grey	1/3	4·7	3·5	2·1	
Indigo	—	c	blue	1/1	5	3·4	2·2	
	—	c	dark blue	2/1	5	4·4	2·8	
	—	w	blue	1/1	5	5	4·4	
	—	w	dark blue	2/1	5	5	4·9	
Indigo and Fustic	Al	w	green	1/1	4·4	4·3	2·9	darkens before fading bluer
	Al	w	dark green	2/1	4·9	4·7	4·0	
Indigo and Quercitron	Al	w	dark green	2/1	4·8	4·1	2·7	fades to blue
Prussian Blue	—	c	pale grey blue	1/1	4·9	4·1	3·6	
	—	s	blue	1/1	4·5	4·0	2·9	darkens
	Sn	w	dark blue	2/1	4·9	4·8	4·8	
	Sn	w	blue green	2/1	3·0	2·8	2·7	darkens to black
	Sn	w	dark blue green	2/1	4·3	4·3	4·2	
Logwood	Fe	c	pale grey blue	1/12	4·0	2·8	1·6	shows a curious 'adjacency effect' (see text)
	Cu	c	pale grey blue	1/12	4·5	2·9	1·6	
	Cu	c	green blue	1/6	4·4	2·8	1·5	
	Sn	c	purple	1/1	1·6	<1	<1	
	Sn	w	dark purple	2/1	4·2	2·2	1·0	
	Al	w	purple blue	1/1	3·4	1·7	<1	
Logwood	Fe, Cu, Al	w	black	1/1	5	4·8	4·6	
and Indigo	Sn	w	black	1/1	5	3·6	2·2	fades to blue
and Fustic	Fe,Cu	w	black	1/1	5	5	4·7	
and Fustic and Indigo	Fe,Cu	w	black	1/1	5	5	5	
Blue Wool Standards		1			2·1	1·2	<1	
		2			3·2	1·9	<1	
		3			3·9	2·5	1·3	
		4			4·7	3·6	2·1	
		5			4·7	4·3	3·1	
		6			5	4·7	3·7	
		7			4·9	4·7	4·1	
		8			5	4·9	4·6	

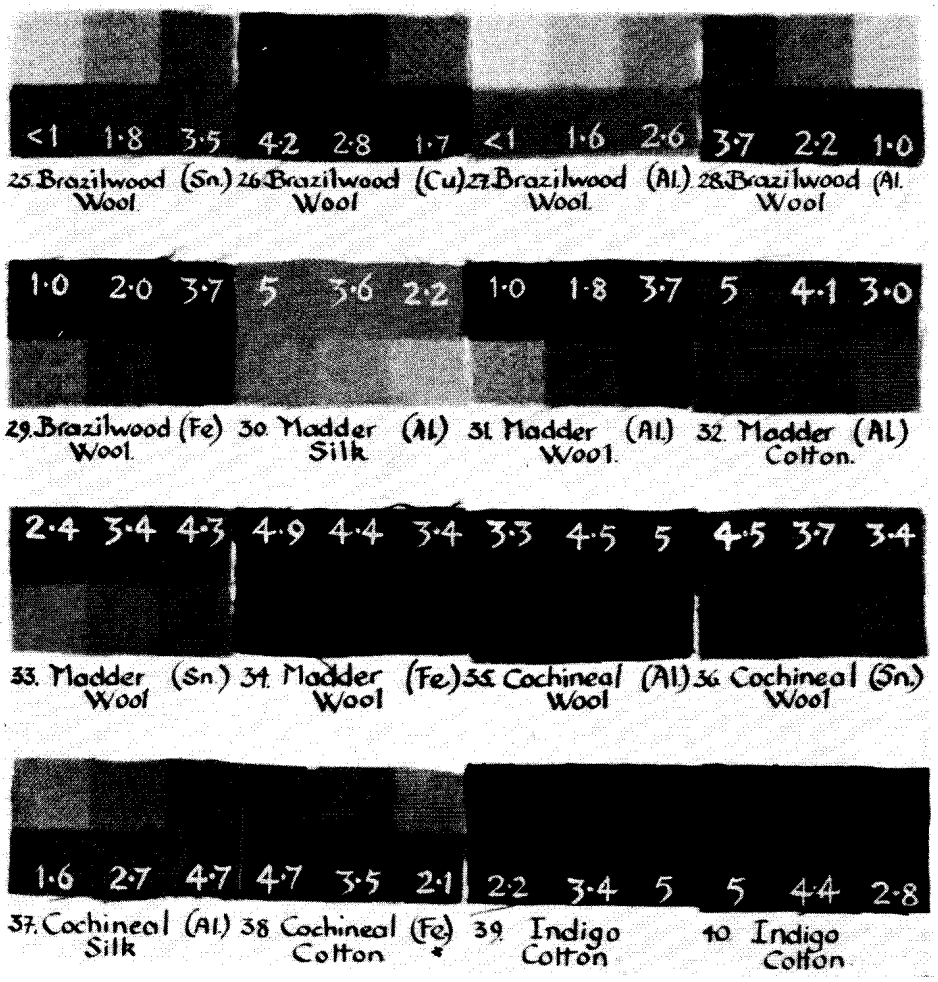

FIG. 1. Some of the faded specimens. The rectangular areas are unexposed. The three square areas on each specimen have been exposed to 7·8, 36 and 91 million lux hours of light from Atlas "Northlight" fluorescent tubes. In all the dyeings illustrated here the palest area has received the greatest light dose. The GS difference between exposed and unexposed dye is written on the unexposed part.

the bright light-fast natural dyes tested are derivatives of anthraquinone.

For permanent museum display very high light-fastness is necessary, and only Indigo on wool, Madder on cotton and some Prussian Blue and Logwood black dyeings would survive long exposure.

There is no light-fast bright yellow natural dye. This is clearly demonstrated by the predominant blue shade of the foliage and grass of old tapestries. Most of the yellow dyes tested became browner and duller as they faded. Weld is an exception and faded without change of hue.

Cochineal became bluer. Iron oxide and some Prussian Blue dyeings darkened continuously during exposure.

Some of the Logwood blues showed a remarkable increase in fading close to the boundary between the exposed and the

protected part. We have no explanation for this effect.

The light-fastness of a dye depends greatly on the mordant and the fibre to which it is applied. Indigo for example, is very much more light-resistant on wool than on cotton; the reverse is true of Madder. Many dyes are more light-fast on a chromium mordant than on any other but this is a modern technique and we did not test its effects. Brazilwood on the other hand is a fugitive dye in all circumstances.

It is a general rule that dyes show a greater resistance to fading when heavily applied to cloth than when lightly applied to give pale tints. Most of those dyes which we have applied by the same method in two strengths appear to show this effect but we cannot be sure because the method of assessment is subjective and probably affected in a systematic way by the depth of colour of the unfaded dye.

THE EFFECT OF LIGHT WAVELENGTH ON FADING

The orange filter gave good protection to nearly all the dyes. The ultraviolet absorber afforded some protection to most. The improvement of light-fastness varied greatly from one dye to another and even for one dye on different fibres. Brazilwood (alum mordant) on cotton, for example, is not much protected by a u.v. filter but the same dye on wool is fairly well preserved.

On average the u.v. absorber gave about 40% improvement in light-fastness (cf. ref. 14), that is, the dye exposed under a u.v. filter would take 1·4 times as long to fade to the same colour as the dye exposed without protection. This figure of course only applies to the particular lamp used. U.v. filters would give a much more noticeable protection against fading in daylight because of its greater proportion of u.v. to visible radiation.

The fading of a dye is caused by radiation of certain wavelengths. The damaging wavelengths vary from one dye to another [15]. For this reason dyes do not generally fade at the same rate in artificial light as in daylight of equal illuminating power. Different artificial light sources vary in their destructive effect on dyes but the relative effects of the two sources used in our experiments cannot be assessed because the exposures were not run under identical conditions. We have not tested the effect of incandescent lamp light.

The spectral dependence of fading is a matter of some interest because the spectral energy distribution of museum light sources can be controlled. There is no doubt that, as a general rule, the damage done by light increases as the wavelength decreases. That is, blue light is more damaging than red. In the case of dyes there is another useful generalization: dyes of low light-fastness are sensitive to light of longer wavelength than dyes of high light-fastness [15]. These statistical generalizations are useful today when several thousand dyes are available, but they are no substitute for experiment on the twenty or so widely used natural dyes.

The experiments reported here are not sufficiently refined to give any quantitative information about this. In the future we hope to report on some fading tests on transparent films coloured with the most widely used natural dyes.

THE RATE OF FADING

The rates of destruction of dyes reported here are, from a museum curator's point of view, very rapid.

There is good evidence that fading depends on the total light energy incident on the dye, regardless of the rate at which it arrives [16]. We have exposed the blue wool standards in a showcase in the Victoria & Albert Museum. The illumination was between 150 and 200 lux from Philips K 34 lamps. After a light dose of just under one million lux hours the first standard had faded to GS 2·2, the second to GS 3 and the third to GS 4.

This part of the experiment is obviously proceeding rather slowly but it suggests that many of the natural dyes can be expected to fade noticeably after a year in a museum showcase. In fact the accelerated tests seem to give an optimistic light-fastness rating.

Under the mild conditions in a museum a light exposure of 70 million lux hours would accumulate in about half a century. After this exposure many dyes would show only the faintest tint of their original colour, or a faint tint of some other colour. Many of the yellows would have become pale brown and even the fastest dyes, Madder, Cochineal and Indigo, would have changed appreciably in colour.

The fading of most dyes becomes slower as fading proceeds [17, 18]. Our dyes also showed this effect, but not to such an extent that their life would be extended beyond that predicted by the fastness rating we have given them. Many of the dyes faded to drabness before the end of the experiments.

Some people, no doubt, will claim that the old dyers had some tricks which ensured a light-fastness superior to that attainable today with the same dyes. There is no evidence for this assertion and very little against it. Kiel and Heertjes [19] tested the light-fastness of Turkey Red (Madder) patterns from old recipe books and found no significant difference between these and modern dyeings.

The failure of many of the very early synthetic dyes to resist destruction by light fostered a nostalgic belief in the excellence of natural dyes. The near impossibility of obtaining these natural dyes nowadays has allowed this always mistaken belief to fossilize into a romantic myth. The two quotations below, separated in time by over half a century, testify to the endurance of prejudice.

'... the prevalent idea that the latter [natural dyes] are fast while the former [synthetic] are fugitive is merely a popular error. This opinion has, however been so long fixed in the popular mind that it is to be hoped the conclusive proof of its fallacy afforded by these experiments will cause it to be finally abandoned' (BA Report [11], 1899).

'Mr Spence said [of the Coventry Cathedral tapestry] that the colours were rich, and would have to be fast, and they had been assured that vegetable dyes would have to be used' (*The Times*, December 21, 1954, p. 3).

We are happy to learn that in the end synthetic dyes were used for this tapestry [20].

THE PRESERVATION OF DYES

There is no way yet known of preserving all dyes from destruction by light. Dyes are substances of great chemical variety; it is unreasonable to expect that any one method will protect all of them against the effect of light.

It has been suggested that dyed materials should be surrounded by an 'inert' gas such as nitrogen or argon. This undoubtedly prevents or retards the fading of many dyes. But not all [5, 21].

A more serious objection to this method is that the stability of all dyes has been evaluated in air. In other environments most dyes may be more stable but some may be less stable. Chevreul (see above) showed that Prussian Blue (a mineral pigment used to colour cloth) fades very rapidly in a vacuum although in air it is very light-resistant. Other pigments such as Vermilion and Chrome Yellow are drastically affected by exposure in a vacuum [22, 23]. The results of Russell and Abney's work [24] on water colours suggests that Madder and Alkanet will fade in an inert atmosphere. We have confirmed Chevreul's observation that Turmeric fades in the absence of air about half as rapidly as in air.

A pre-requisite for keeping a piece of dyed material in an inert gas is therefore a complete knowledge of all the dyes, pigments and fibres present and a knowledge of their permanence in such conditions.

WAYS OF REDUCING FADING

There are several other ways of reducing the effect of radiation on dyes.

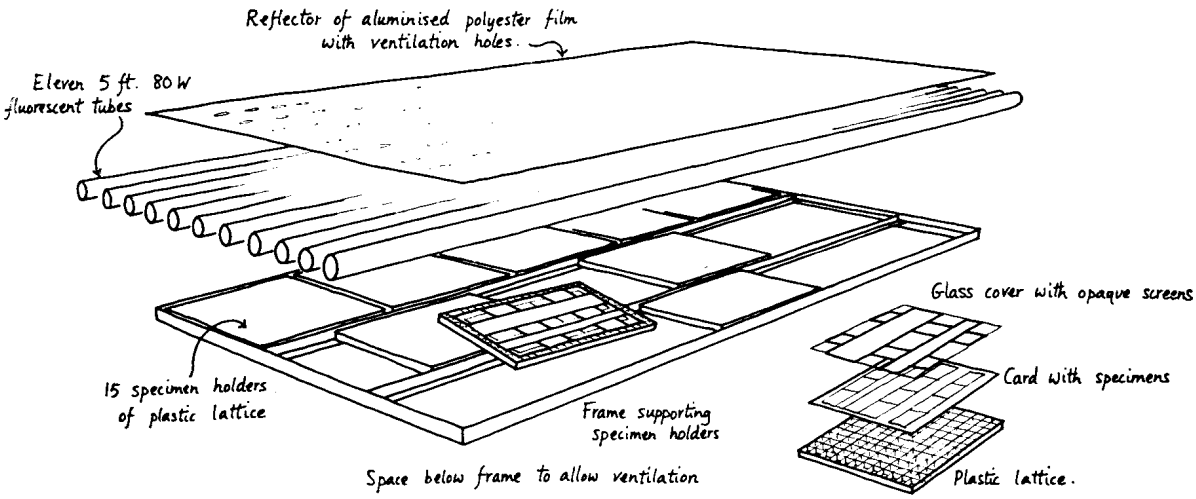

FIG. 2. The design of the fading apparatus. The vertical separation of the parts is exaggerated.

Ultraviolet radiation should be removed because it causes some fading but provides no illumination.

The spectral energy distribution of the light can be controlled. This cannot be done effectively until the spectral sensitivities of the irradiated dyes are known.

A reduction in the ambient relative humidity will slow the fading of many dyes, particularly on cotton.

These effects, and others which alter the light-fastness of dyes, have been reviewed by Giles and McKay [17] and by Giles [18].

CONCLUSIONS

The poor light-fastness of nearly all the natural dyes is established beyond question and their preservation in the presence of light is not yet possible.

Fifty years of permanent exhibition in the dimmest tolerable conditions would destroy the yellow natural dyes and the red dye-woods and impair the brilliance of light dyeings of Madder and Cochineal. Indigo on cotton would fade and only the blue of Indigo on wool and some of the browns and blacks would survive. This is why browns, heavy red and Indigo blue are the dominant colours of museum textiles.

There are many modern dyes of fastness 7 or above. But the choice of a dye is governed by many other factors and the average light-fastness of dyes on modern cloth is probably still only 4 to 5 [25].

Our conclusion is that no valuable textile in good condition should be permanently displayed unless all the dyes are known to have a light-fastness above 6.

It is possible to arrange that a textile in a showcase is illuminated only when a visitor pushes a button or walks close to the case. The incident light energy would be proportional to the popularity of the exhibit. Assuming an enlightened public taste, this is not the best way to preserve that which is most worth preserving. But it is much better than permanent illumination.

We think it important that if the dyes cannot be preserved some record of their original colour should be available. Colorimetry is becoming very accurate. The exact colours of dyes should be recorded before they are displayed.

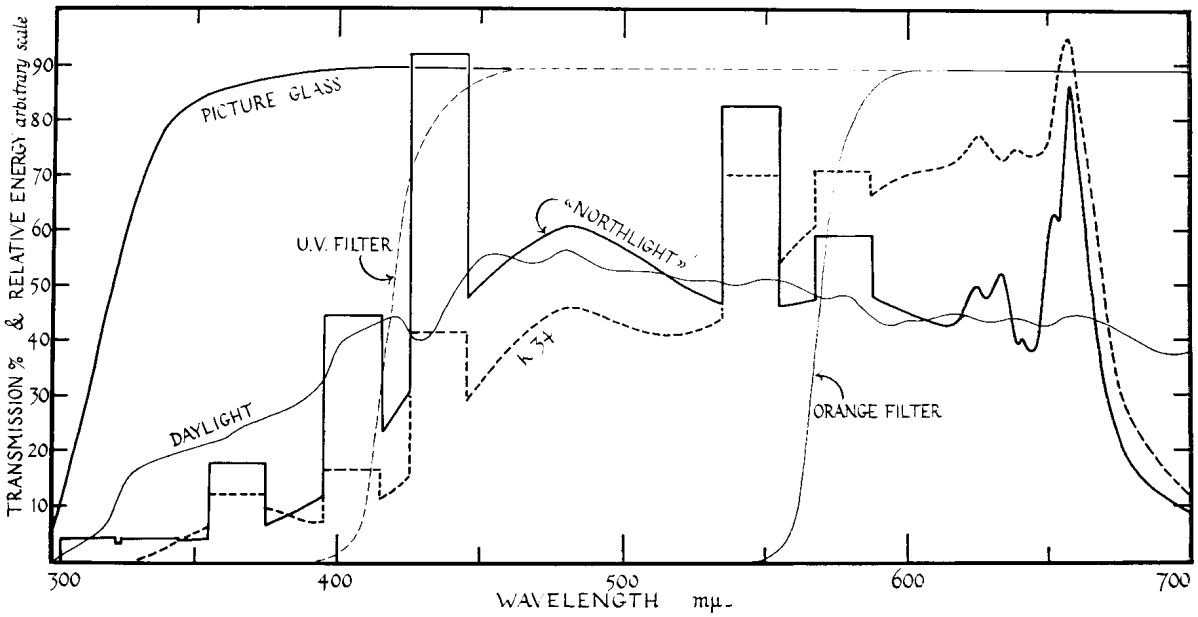

FIG. 3. The spectral transmission of the filters and the spectral energy distribution of the light sources used in these experiments. S.e.d. of fluorescent lamps taken from manufacturers' data. Energy average s.e.d. of daylight from calculation by Padfield [5].

EXPERIMENTAL DETAILS

The dyes were applied to bleached cotton shirting, silk 'grey cloth', degummed in the laboratory, and 'Nun's Veiling' woollen cloth. The dyes were used in their commercial state without purification because many are mixtures and the colour changes on fading are not necessarily due to the alteration of a single substance.

Most of the dyes are mordant dyes. These have no affinity for the fibres but form insoluble compounds with salts of aluminium, iron, tin or copper previously deposited in and among the fibres. There are many variations of detail between published ways of applying the same dye. Except for the work by Kiel and Heertjes already mentioned there is little evidence about the identity of the products or the consequent variation of light-fastness. We generally used the methods of Hummel [26].

Indigo was applied by a modern method using sodium hydrosulphite as the reducing agent. The mineral pigments were applied by conducting precipitation reactions within the cloth.

THE FADING APPARATUS

The design of the fading apparatus is shown in Fig. 2. The lamps were changed about every 4000 hours. The spectral energy distributions of the two lamps and of average London daylight are shown in Fig. 3. Superimposed on these are the transmission curves of the various filters used to screen the dyes.

The illumination was measured with a SEI photometer. It varied between 20 and 16 thousand lux, depending on the position in the apparatus and the age of the lamps.

The dyed cloth samples were laid on card sparingly treated with 'Cellofas B' solution as an adhesive. Parts of the specimens were shaded by screens of black paper laminated to aluminium foil. The foil faced the light. The cards and cloth were covered with thin

picture glass and fastened to pieces of plastic lattice. These in turn were mounted on an open frame in such a way that air could circulate through the uncovered spaces round the edges of the lattices. The lattices were moved round regularly so that all the specimens received the same total light energy.

It is difficult to control the temperature and relative humidity around irradiated dyes. We merely arranged good convective ventilation. The dyes were consequently subjected to a rather higher temperature than those in the museum gallery. The ambient temperature was generally between 16° and 20°C. The black panel temperature, that is the temperature reached by an irradiated black-dyed specimen, was usually below 30°C but rose to 35°C on a few very hot summer days. Paler dyes would have remained much cooler.

The temperature coefficient of most fading reactions is known to be small but a systematic error may have been introduced by the rather low effective humidity around the dyes. This would give a light-fastness in our experiments greater than the value in normal exposure, particularly for dyes on cotton.

We claim no great accuracy in our experiments and aim to give merely the approximate magnitude of the light-fastness of dyes. Dyes are rather variable in their behaviour and their light-fastness depends on the depth of dyeing and on many environmental factors. Rawland [3] found that the daylight energy required to fade BS 7 to GS 4 varied, in different exposures, between 18 000 and 149 000 langleys (cal/cm^2).

The various environmental influences on the light fastness of dyes in accelerated fading tests have been reviewed by Brunnschweiler [26].

The fading of the dyes was evaluated by six members of the staff of the Conservation Department of the Victoria & Albert Museum. They compared the contrast between the faded and unfaded portions of the dye with the patterns of the standard grey scale and judged the facing to the nearest half unit. The average of their assessments is given in the Tables. The six observers usually agreed within one unit.

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GLOSSARY

The colours and numbers refer to the natural dye section of the Colour Index, 2nd edn. unless the full CI description is given. Many of these dyes are obtainable from several species. Those listed below appear to have been the commonest sources of dyes used in Europe but the list is compiled from literature citations and is not critical.

Alizarin Lake	pigment red 83, Aluminium lake of 1:2-dihydroxyanthraquinone, the principal colouring matter of Madder.
Alkanet	red 20, root of *Anchusa tinctoria*.
Annatto	orange 4, seed pods of *Bixa orellana*.
Barwood	red 22, wood of *Baphia nitida*.
Brazilwood	red 24, wood of *Caesalpina braziliensis*.
Camwood	red 22, similar to Barwood.
Carmine Lake	an indefinite title, usually applied to Cochineal lakes but sometimes to lakes of other dyes.
Chay root	red 6, *Oldenlandia umbellata*.
Chrome Yellow	pigment yellow 34, lead chromate.
Cochineal	red 4, *Coccus cacti*.
Coscinium	yellow 18, root of *C. fenestratum*.
Cutch	brown 3, *Acacia catechu* &c.
Evodia	*E. meliaefolia*.
Flavin	yellow 10, extract of Quercitron
Gardenia	yellow 6, *G. florida*.
Indigo	blue 1, leaves of *Indigofera* species. We used synthetic Indigo, vat blue 1.
,, sulphonated	blue 2.
Jack wood	yellow 11, *Artocarpus intergrifolia*.
Kamala	orange 2, fruit of *Mallotus philippensis*.
Kermes	red 3, *Kermococcus vermilio*.
Lac dye	red 25, *Coccus laccae*. or *C. ilicis*.
Limawood	red 24, *Caesalpina echinata*.
Logwood	black 1, *Haematoxylon campechianum*.
Lo Kav	green 1, *Rhamnus utilis*.
Madder	red 8, root of *Rubia tinctorum*.
Mang Kudu	red 19, *Morinda umbellata*.
Morinda	red 18, root of *M. citrifolia*.
Munjeet	red 16, root of *Rubia cordifolia*.
Old Fustic	yellow 11, *Chlorophora tinctoria*.
Orchil	red 28, various lichens.
Peachwood	see Limawood.
Persian Berries	yellow 13, *Rhamnus saxatilis*.
Prussian Blue	pigment blue 27, complex iron cyanide.
Quercitron	yellow 10, bark of *Quercus nigra*.
Safflower	red 26, petals of *Carthamus tinctoria*.
Saffron	yellow 6, stigma of *Crocus sativus*.
Sapanwood	see Limawood.
Sophora	yellow 10, *S. japonica*.
Tesu	yellow 28, flowers of *Butea frondosa*.
Turkey Red	see Madder and ref 19.
Turmeric	yellow 3, root of *Curcuma tinctoria*.
Ventilago	orange 1, root bark of *V. madraspatana*.
Vermilion	pigment red 106, mercuric sulphide.
Weld	yellow 2, *Reseda luteola*.
Young Fustic	brown 1, wood of *Rhus cotinus*.

The symbol in brackets after each dye in Tables II-IV shows the metal whose oxide or basic salt forms the mordant for the dye.
Al: aluminium, Cu: copper, Fe: iron, Sn: tin.

The *langley* is one calorie of solar energy per square centimetre. The *lux* is the unit of illumination. It is the radiant energy incident upon a surface per unit time weighted according to the luminous efficiency at each wavelength.

RÉSISTANCE À LA LUMIÈRE DES TEINTURES NATURELLES

Examen des reseignements sur la résistance à la lumière des teintures naturelles (voir tableau 1). Description de nouvelles épreuves sur la résistance de plusieurs pigments à la lumière des lampes fluorescentes (voir tableaux 3 et 4).

Presque tous les colorants naturels ont une résistance à la lumière inférieure à la norme 'British Standard grade 5'. La plupart ont une résistance inférieure à 4. Presque tous les colorants naturels passent sérieusement lorsqu'ils sont exposés à 50 millions de lux-heures de lumière artificielle ou à une dose beaucoup plus faible de lumière naturelle. Dans bien des musées, une décoloration sérieuse de la plupart des colorants se produirait en moins de 50 ans.

Il n'y a pas de méthode très efficace pour réduire le taux de décoloration. Des dispositifs qui absorbent les rayons ultra-violets, placés sur les sources de lumière, permettent d'augmenter de façon intéressante la résistance à la lumière et à la plupart des colorants, mais non pas de tous. Si l'humidité relative est basse, la décoloration est régulière. Si l'on place tous les articles exposés dans des boîtes contenant un gaz inerte, la plupart des colorants résistent mieux, mais la décoloration

de certains pigments utilisée sur des textiles en est accélérée. Il ne faudrait pas exposer de façon permanente des textiles de valeur dont les colorants ont une résistance à la lumière inférieure à la norme British Standard 6.

DIE LICHTBESTÄNDIGKEIT NATÜRLICHER FARBSTOFFE

Angaben über die Lichtbeständigkeit natürlicher Färbestoffe befinden sich in Tabelle II. Über Versuche mit der Beständigkeit verschiedener Farbstoffe bei Leuchtstofflampenlicht wird ebenfalls berichtet (siehe Tabellen III and IV).

Fast alle natürlichen Färbestoffe haben eine Lichtbeständigkeit, die unter dem Gütegrad 5 der Britischen Norm liegt. Die meisten besitzen sogar eine Lichtbeständigkeit von weniger als 4. Fast alle natürlichen Farbstoffe bleichen sehr stark, wenn sie 50 Millionen Lux-Stunden künstlichem Licht ausgesetzt sind; bei Tageslicht geht der Bleich-Prozess wesentlich schneller vor sich. In den Ausstellungsräumen der meisten Museen würden die meisten Farbstoffe innerhalb von weniger als fünfzig Jahren bis zu einem gefährlichen Grade verbleichen.

Es gibt keine sehr erfolgreichen Methoden zur Herabsetzung ser Bleich-Geschwindigkeit. Durch Anbringen von Ultraviolet-Filtern, über den Lichtquellen, kann die Lebensdauer mancher, aber nicht aller Farbestoffe beträchtlich verlängert werden. Auch niedrige relative Luftfeuchtigkeit erhöht die Lichtbeständigkeit. Für die meisten Färbestoffe ist es von Vorteil, wenn die Ausstellungsvitrinen mit einem Schutzgas gefüllt sind; einige Färbestoffe auf Geweben aber verbleichen dadurch schneller. Wertvolle Textilien mit einer Lichtbeständigkeit von weniger als 6 (Britische Norm) sollte man nicht ständig ausstellen.

LA STABILITÀ ALLA LUCE DEI COLORANTI NATURALI

Nella Tabella II si presenta una rassegna delle informazioni disponibili sulla stabilità alla luce dei coloranti naturali. Nelle Tabelle III e IV si riportano i dati di nuove prove sulla stabilità alla luce di vari coloranti condotte con lampade fluorescenti.

Quasi tutti i coloranti naturali hanno una stabilità alla luce inferiore alla Norma Britannica Grado 5. La maggioranza ha una stabilità inferiore a 4. Quasi tutti i coloranti naturali scolorano molto nel corso di un'esposizione a 50 milioni di lux ore di luce artificiale o a una dose molto meno intensa di luce solare. In molti musei si verificherebbe uno scoloramento sensibile della maggior parte dei coloranti in meno di 50 anni.

Non esiste ancora un metodo efficace ridurre il ritmo di scoloramento. Sistemando assorbitori ultravioletti sulle sorgenti di luce si ha un notevole aumento nella stabilità alla luce della maggioranza dei coloranti, ma non di tutti. Una bassa umidità relativa diminuisce lo scoloramento. L'esposizione in bacheche riempite di un gas inerte rende piú stabile la maggior parte dei coloranti ma accelera lo scoloramento di alcuni pigmenti impiegati sulle stoffe. Tessuti di valore i cui coloranti abbiano una solidità alla luce inferiore alla Norma Britannica 6 non vanno esposti a titolo permanente.