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Photographic Flash: Threat or Nuisance?

DAVID SAUNDERS

Most museums and galleries, including the National Gallery, do not permit visitors to take photographs using electronic flash. It is assumed by many that this prohibition is to protect the paintings from the damaging effects of repeated exposure to photographic flash, since light and ultra-violet radiation are known to damage pigments and to discolour media, varnishes and other organic materials in works of art. Despite the high light output from a photographic flash, the duration of a single pulse is extremely short, typically around 0.001 seconds. As a result, the overall light exposure from a single flash from a modern photographic flash unit is relatively small, of the order of 600lux.s (or 0.17lux.h which is equivalent to *f8* at 100ASA).[1] For comparison, the recommended annual exposure level at the Gallery (for oil and tempera paintings) is 600,000lux.h, which would be equivalent to approximately three and a half million 'flashes'.

This equivalence between illumination at around 200lux (the recommended level for moderately sensitive museum objects) throughout the year and a number of short pulses of light from a photographic flash holds only if the so-called reciprocity law is obeyed. According to this law, the damage caused by one hour of illumination at a level of 1,000lux is equal to that caused by ten hours at a level of 100lux and so on. Since reciprocity assumes that each photon of light has an equal potential to cause damage, it is worth describing the probable mechanism of light-induced damage before proceeding.

Damage by photolytic processes generally

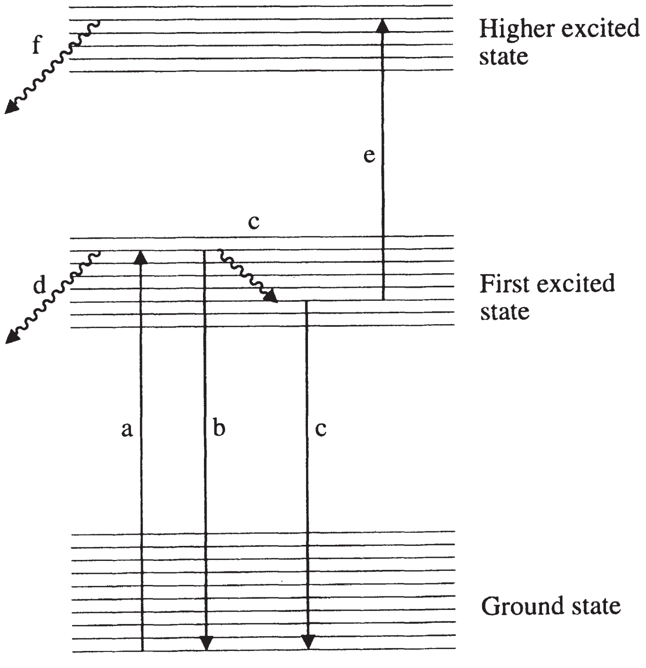

Fig. 1 Schematic representation of some of the light-induced excitation pathways for a molecule: **a**, excitation of the ground state to a first excited state by absorption of a photon; **b**, return to the ground state from the first excited state; **c**, return to the ground state by re-emission of radiation from a lower vibrational energy level; **d**, dissociation or chemical reaction of the first excited state; **e**, absorption of a second photon producing a higher energy excited state; **f**, dissociation or chemical reaction of the higher energy excited state

occurs when a photon of light is absorbed by a molecule. The absorption of this energy raises a molecule from its ground state to an excited state (Fig. 1a). While most of the molecules in the excited state will rapidly return to the ground state, re-emitting the absorbed energy as radiation of the same (Fig. 1b) or lower (Fig. 1c) energy or as heat, a small proportion of the excited molecules will undergo an irreversible change, leading to degradation of the original material (Fig. 1d). It is also possible that a molecule in the excited state may be further excited by the absorption of an additional photon (Fig. 1e), which may initiate a different degradation process (Fig. 1f). If the rate at which photons arrive is high and the lifetime of the excited state is sufficiently long, molecules will be excited more quickly than they return to the ground state. Under these circumstances, the larger concentration of molecules in the first excited state makes the absorption of a second photon by these reactive intermediates more likely, increasing the possibility of degradation by this pathway (Fig. 1f). It is these so-called sequential two-photon (or biphotonic) processes, which may be initiated when a material is exposed to high-intensity light, even of short duration, that are the main hazard of photographic flash.

The energy gap between the first and second excited states will not usually be the same as that between the ground state and the first excited state. As a result, those wavelengths of light which are absorbed most strongly by the ground state (and to which the colour of the material is due) may not be responsible for the deterioration caused by absorption of a second photon.

It is not necessarily those colorant molecules which deteriorate most rapidly by excitation from the ground state that will be most susceptible to biphotonic processes. For this reason, a previous study by Hanlan into the effect of photographic lamps on materials in works of art examined a number of colorants which are not generally considered to be prone to light-induced deterioration.[2] Among these colorants were the inorganic pigments ultramarine and cadmium red and several modern synthetic organic pigments, including phthalocyanine green and blue, arylamide yellow, toluidine red and a rhodamine-based pink; all were painted out in an acrylic medium. In addition, Hanlan included ISO blue wool standards numbers 1 to 8 in his experiment and exposed another set of samples to strong fluorescent light for comparative purposes.

The experiments described below were designed to test the reciprocity law as applied to the light-induced damage of certain artists' pigments, known to be fugitive when exposed to light. It was hoped to determine whether any biphotonic processes affected the rate of colour change under two very different types of light exposure: in a Gallery room at either *c.*80 or *c.*200lux for one year, and to an equivalent dose from a photographic flash.

Experimental

Sample preparation

Five identical sets of samples were prepared. Each sample set comprised ISO blue wool standards[3] numbers 1 to 3 and 22 artists' pigments in watercolour medium. A full list of the pigments included in each sample set can be found in Table 1; details of the preparation of those pigments which have not been described previously[4] are given in the Appendix.

With the exception of sap green and gamboge, which did not require the addition of a gum medium, all the other dry pigments were prepared by grinding in a freshly made solution of gum arabic and diluting with distilled water. The watercolour paint was applied as a thin wash on Whatman 'Silversafe' 200gm^{-2} conservation grade paper. Samples from the Winsor & Newton, Ackerman and Roberson watercolour pans were painted out as thin washes, using distilled water. The Silversafe paper is buffered to a pH of six, which is high enough to prevent any undesirable colour change in the samples of litmus.

Light exposure

One of the five sets of samples was used as a dark control. It was stored under the same conditions as the other samples in an air-conditioned room at a temperature of 21±2°C and a relative humidity of 55±5%.

A second set of samples was placed opposite a Metz *Mecablitz 45 CT-1* photographic flash unit (Fig. 2). The flash was fitted with the ultraviolet filter provided by the manufacturers. The variable control on the unit was adjusted to give

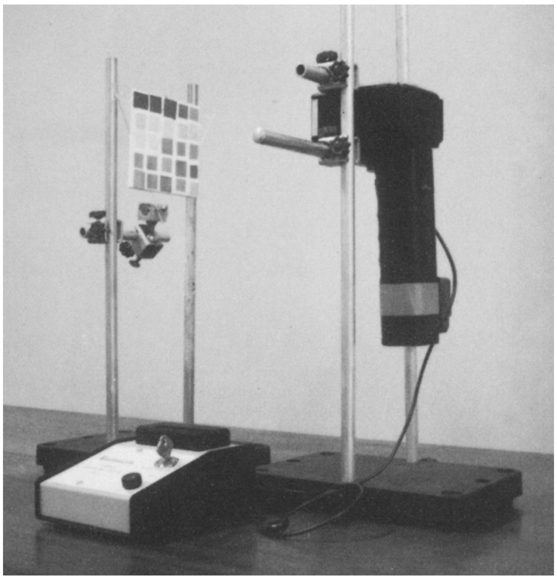

Fig. 2 The experimental equipment for exposing colorant samples to light from a photographic flash gun. The samples are secured to a white ceramic tile to the left, opposite the flash gun; the trigger/counter unit is at the bottom in the centre.

an exposure of 650 lux.s per flash. The flash gun was triggered every seven seconds; this time interval proved sufficient to allow the capacitor to recharge fully between exposures.[5] Because the equipment was to be used over a prolonged period and to ensure that the capacitor recovered between exposures, the flash unit was powered with mains electricity, not using the internal batteries. The sample set was exposed to approximately 4,000,000 flashes.

A third set of samples was placed in one of the Gallery rooms in an area where paintings in oil medium are displayed. The lighting is provided by a mixture of daylight and tungsten halogen lamps, both of which are filtered to remove virtually all ultra-violet radiation. The samples were attached to a white ceramic tile which was secured to the wall at the same height as the adjacent paintings (*c.*1.8m from the floor). This location was chosen because the light levels in the room are constantly logged by the Gallery's environmental control system. As a result it was possible to assess the number of lux.h to which the samples had been exposed by examining this record. The level in this room is maintained at approximately 200 lux during Gallery opening hours; over the eight months of the experiment the samples were exposed to 391k lux.h. Another set of samples was placed in a nearby room, lit only by tungsten halogen lamps, which is maintained at around 80 lux during Gallery opening hours. This area is also monitored constantly; the total exposure during the experiment was 213k lux.h.

Finally, a fifth set of samples was exposed to photographic flash under the same conditions, but without an ultra-violet filter.

Colour measurement

The colour of each sample was recorded before exposure and periodically during the experiment. The exposure of samples to photographic flash could be suspended temporarily by setting the selector switch on the trigger/counter unit to 'hold'; the counter is not reset by this action. All the colour measurements were made using a Minolta CR200 chroma meter fitted with a CR200 measuring head, which provides diffuse illumination and measures the reflected light perpendicular to the surface of the sample (this standard measuring geometry is referred to as d/0 and is suitable for measuring matt samples, for example those in watercolour medium). The CR200 head measures a sample area 8mm in diameter.

The microprocessor in the meter was used to convert these measurements into Commission International de l'Eclairage (CIE) L^*, a^* and b^* coordinates under the CIE standard illuminant D65.[6] These data were transferred from the meter for permanent storage on a computer.

The colour difference (ΔE) between the sample before exposure and at each measurement during the experiment was calculated according to British Standard 6923:1988; a ΔE of one corresponds to a just perceptible colour difference.[7] The error in measurement was $\Delta E \pm 0.25$.

Results and discussion

The colour changes measured for the dark control samples were all negligible in the context of the error introduced by the measurement process. These results suggest that there were no temperature- or humidity-induced colour changes.

For each sample the colour change (ΔE) was plotted against total light exposure. For the two sample sets in Gallery rooms the exposure was determined directly from the environmental record for the appropriate room. The flash exposure was calculated by multiplying the number

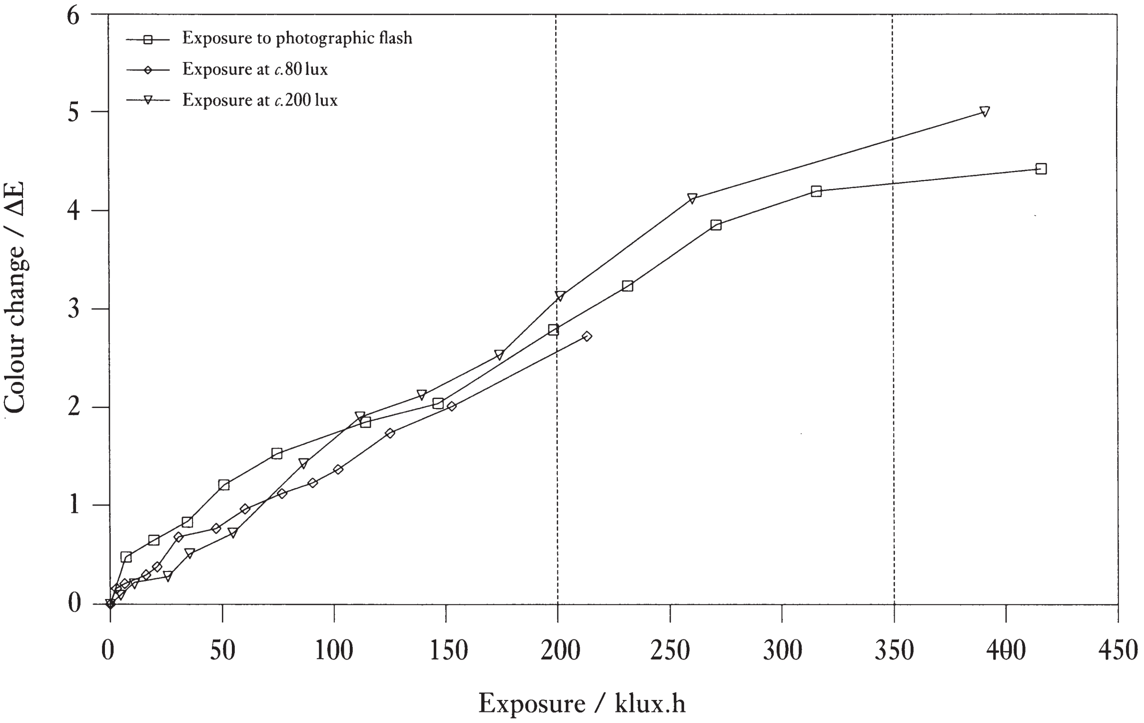

Fig. 3 Representative graph of colour against exposure for cochineal lake 5 when exposed to photographic flash, light at *c*.200 lux and light at *c*.80 lux. The broken lines indicate exposures of 200 and 350 klux.h, corresponding to the data in Table 1.

of flashes by the exposure per flash. As the light exposure per flash decreased by *c*.10% during the course of the experiment a correction was applied to these data. A typical plot of ΔE against exposure is shown in Fig. 3, for cochineal lake 5 in this case. For each sample the colour changes after 200klux.h and 350klux.h were determined by interpolation; an exposure of 350klux.h was not reached by the samples from the room where the light level was *c*.80lux. The interpolated data are presented in Table 1.

Several of the samples show very small colour changes, which are barely above the level of experimental error, particularly after only 200klux.h. Indigo, gamboge, alizarin crimson and some of the kermes and lac lakes fall within this category.

Most of the remaining colorants show similar colour changes after equivalent exposure to photographic flash or constant illumination; in some cases the colour change is greater for the former, in other cases the latter appears to be marginally more damaging. In the same way there are slight differences in the colour change caused by equivalent exposure to constant illumination at different levels (80 and 200lux). Only for the brasilwood lake and kermes lake KD1 are there appreciable differences between the colour change caused by photographic flash and that caused by exposure to normal gallery lighting: in each case exposure to photographic flash appears to be less damaging than exposure to ambient light levels. Why these lake pigments should behave in this fashion is not clear, particularly since kermes lake KD1 is prepared in a similar manner to kermes lake KT1.

Those samples which were exposed to photographic flash without an ultra-violet filter showed, as expected, a slightly greater colour change. After approximately 1,500,000 flashes the colour changes (ΔE) for the samples exposed to unfiltered light were 10–15% greater than those for exposure with ultra-violet filtration. Unfortunately, it was not possible to complete this part of the experiment, due to failure of the flash unit.

It is interesting to compare these results with those obtained by Hanlan. With the exception of Rose red (rhodamine phosphotungstate), and to a lesser extent Hansa yellow (arylamide yellow), none of the colorants in his study was affected by an exposure of 336klux.h, although blue wool standards numbers 1 and 2 showed detectable colour changes. Hanlan used the

Table 1 Colour change for colorant samples on exposure to photographic flash or to ambient light in Gallery rooms

Sample	Reference	Colour change (ΔE) after 200klux.h			Colour change after 350klux.h	
		Photographic flash	Exposure at 200lux	Exposure at 80lux	Photographic flash	Exposure at 200lux
Blue wool standard #1	3	4.91	4.81	3.88	10.08	9.68
Blue wool standard #2	3	1.67	1.71	1.33	3.38	3.83
Blue wool standard #3	3	0.91	0.41	0.76	0.75	0.34
Indigo (Ashill Studio)	4	0.51	0.36	1.36	0.45	0.67
Indigo (Winsor & Newton)	4	0.44	0.53	0.51	0.89	0.48
Quercitron lake (Q1)	4	1.42	1.01	1.5	2.45	2.04
Quercitron lake (Winsor & Newton)	4	1.51	1.52	0.69	2.84	3.08
Buckthorn lake (Bu3)	4	3.23	2.46	1.99	4.85	5.37
Buckthorn lake (Bu1)	4	2.14	1.89	1.74	4.26	4.18
Weld lake (WW1)	4	0.96	0.79	0.67	1.68	1.52
Gamboge (Ackerman)	Appendix	0.18	0.64	1.17	0.63	0.64
Gamboge (Winsor & Newton)	Appendix	0.31	0.51	0.57	0.86	0.65
Cochineal lake (C4a)	4	2.51	1.88	1.76	4.50	4.53
Cochineal lake (C5)	4	2.81	3.09	2.63	4.31	4.72
Cochineal lake (C8)	4	2.83	2.94	2.52	5.47	6.11
Kermes lake (KD1)	4	0.82	2.28	2.65	1.71	4.01
Kermes lake (KK1)	4	0.44	0.76	0.81	1.12	1.29
Kermes lake (KT1)	Appendix	0.77	0.54	0.37	2.24	1.91
Lac lake (LL1)	4	0.81	0.81	0.63	1.03	1.67
Lac lake (LT1)	Appendix	1.72	1.68	1.55	3.53	3.81
Brasilwood lake (BrBrm)	4	1.25	3.23	3.32	2.37	6.27
Madder lake (MM1)	4	0.48	0.74	0.99	0.53	1.33
Alizarin crimson (Roberson)	4	0.39	0.13	0.36	0.28	0.29
Litmus (Li2)	4	12.30	15.30	15.62	20.00	26.53
Sap green (SGj)	4	2.80	2.77	2.19	4.90	5.33

Table 2 Colour change in blue wool standards numbers 1 and 2 under different conditions of exposure

Illumination	Colour change Δ_{xy} after 336klux.h	
	Blue wool #1	Blue wool #2
25,000 flashes [Hanlan]	0.121	0.080
25,000 flashes with ultra-violet (uv) filter [Hanlan]		0.040
Fluorescent light [Hanlan]	0.060	0.015
c. 2,000,000 flashes with uv filter	0.031	0.011
Daylight and tungsten halogen light with uv filter	0.026	0.010

change in the CIE x and y coordinates as a guide to the magnitude of colour change.

By converting data from the current experiment into CIE xy and interpolating to determine a change after 336k lux.h, it is possible to derive a comparison between the colour change for blue wool standards numbers 1 and 2; these data are presented in Table 2.

The colour changes observed by Hanlan are all rather larger than those in the current experiment. It may be that the absence of ultra-violet filtration in all but one case contributes to this effect, but the results obtained for the sample set exposed to unfiltered flash in the present experiment suggest that the effect is not so great as to cause such a difference in colour change. Hanlan suggested that the difference in the degree of fading under a flash lamp and constant fluorescent illumination might be caused by the different spectral composition of the two sources and the way in which these interacted with the blue colorants in the ISO standards. A recent study of the effect of light of different wavelengths on colour change in a number of colorants, including blue wool standards numbers 1 to 3, supports this suggestion.[8] The results from the current experiment, which show only slight differences in the colour change under different illuminants, add no further weight to this proposition.

Another possible reason why the considerable difference in colour change observed by Hanlan for blue wool standards numbers 1 and 2 is not evident in the current experiment might be the difference in output of the flash sources used. Hanlan's flash produced 4500 foot candle secs, which is equivalent to approximately 48,500 lux.s, 75 times more light output than the 650 lux.s from the *Mecablitz* flash unit. Perhaps the very intense light from the former was sufficient to initiate a biphotonic degradation not evident at the lower light levels associated with the modern flash unit or illumination in a gallery room.

Conclusions

The results presented above suggest that for the colorants examined there is a reasonable correlation between colour change and total light exposure; that is, reciprocity is followed. There is nothing to suggest that the light level produced by a modern photographic flash gun is any more damaging than an equivalent dose of light delivered gradually while an object is on display. In the past it was feared that photographic flash bulbs might explode, showering the surface of the painting with fragments of glass but, with modern equipment, this type of incident is extremely unlikely. Although it seems that there is no peculiar hazard associated with photographic flash, each time a material is subjected to a flash a small, but finite, deterioration occurs, in addition to that suffered by routine display in an illuminated gallery.

It is probable that certain objects will attract more amateur photographers than others, and that these will be particularly prone to increased light exposure if flash is permitted. To this must be added the considerable nuisance caused to other visitors and to the security staff who remain in the gallery throughout the day.

Conversely, flash photography should be encouraged for professionals, since it invariably requires a lower total light exposure. The main reason for this is that the powerful tungsten halogen or discharge lamps used for photography are switched on while light levels are measured and between 'exposures'. The flash unit, on the other hand, emits light only while the shutter is open; there is no 'wasted light'. Accordingly, the National Gallery's rules for professional photographers permit the use of flash up to a limit of 1250 lux.s per exposure (equivalent to *f* 22 at 100ASA) and stipulate that an ultra-violet filter must be used.[9]

Acknowledgements

The author is extremely grateful to Jo Kirby for preparing the majority of the lake pigments used in these experiments and for her critical and bibliographic advice. Paul Cockram of Electrosolutions designed and manufactured the trigger/counter unit used in this study.[10]

Appendix

The preparation of those pigments which are not commercially available from artists' colourmen was based on recipes from the early fifteenth to the early nineteenth centuries. All but the three preparations given below have been described in detail elsewhere.[11] All lake pigments were prepared on a substrate of hydrated alumina unless otherwise stated.

Lac lake LT1 was prepared from stick lac, *Kerria lacca* Kerr, supplied by Ashill Colour Studio, Shefford, Bedfordshire. The lake was prepared in the same manner as lac lake L2, except that the dyestuff was extracted from the stick lac with an alkali prepared from hardwood ash according to the method given by Rosetti.[12]

Kermes lake KT1 was prepared by extracting the colorant from wool shearings that had been dyed using *Kermes vermilio* Planchon, also supplied by Ashill Colour Studio. The lake is identical to kermes lake KD1, except that the alkali used in the preparation was prepared from hardwood ash as before; in this case the alkali was allowed to stand over quicklime (calcium oxide), thus converting the potassium carbonate component of the wood ash to potassium hydroxide.[13]

Gamboge is a yellow gum-resin exuded from the cut bark of *Garcinia morella* Desr., a small evergreen found in Sri Lanka and elsewhere in South-East Asia. It comprises an acetone-soluble resin (73%) and a water-soluble polysaccharide gum (27%), the latter permitting the solidified material to be used directly as a watercolour pigment. The principal colouring matter is *cis*- or *trans*-gambogic acid with morellic and *iso*-morellic acids as minor components.[14]

Notes and references

1. The exposure is the product of the light level (illuminance) and the time for which an object is exposed at this level. The SI units of illuminance are lux, although illuminance is sometimes quoted in foot candles; one lux is one lumen per square metre whereas one foot candle is one lumen per square foot, thus 1 foot candle = 10.764 lux or 1 lux = 0.0929 foot candles. The SI unit of time is the second and flash exposure is generally quoted in lux.s (lux seconds). It is sometimes more convenient, however, to refer to light exposure in lux hours (lux.h) or kilolux hours (klux.h): 1 klux.h is 1,000 lux.h or 3,600,000 lux.s.
2. J.F. Hanlan, 'The effect of electronic photographic lamps on the materials of works of art', *Museum News,* Vol. 48, No. 10, June 1970, pp. 33–41.
3. British Standard 1006:1990 (issue 2, October 1992), *British Standard methods of test for colourfastness of textiles and leather*, British Standards Institution, Milton Keynes 1992, B01/1-7.
4. The preparations of the majority of the pigments used in this study are given in D. Saunders and J. Kirby, 'Light-induced colour changes in red and yellow lake pigments', *National Gallery Technical Bulletin*, 15, 1994, pp. 79–97, and D. Saunders and J. Kirby, 'Wavelength-dependent fading of artists' pigments', *Preventive Conservation: Practice, Theory and Research*, ed. A. Roy and P. Smith, IIC, London 1994, pp. 190–4.
5. The flash unit was connected to an Electrosolutions 'Flashgun Trigger and Counter Unit' manufactured by Electrosolutions Ltd, 18 Roman Way, Stoke Bishop, Bristol BS9 1SH. The unit is battery powered and provides a trigger pulse to the Metz *Mecablitz 45 CT-1* photographic flash. The time interval between pulses can be adjusted in the range 1–30 seconds. An LCD display gives a record of the number of pulses delivered. The main switch has four positions: 'off', 'reset', 'hold' and 'count'. During the experiment the switch is set to 'count'. When a set of colour measurements are to be made, 'hold' is selected, which suspends the transmission of trigger signals to the flash unit while maintaining the cumulative value on the display. When colour measurement is complete, the switch is set to 'count'. Only at the end of the experiment is the counter set to zero by selecting 'reset'.
6. Commission Internationale de l'Eclairage, 'Recommendations on uniform color spaces, color difference equations, psychometric color terms', Supplement No.2 to *CIE Publication No.15 (E-2.3.1), 1971/(TC-1.3)*, 1978.
7. British Standard 6923:1988, *British Standard method for calculation of small colour differences*, British Standards Institution, Milton Keynes 1988.
8. See D. Saunders and J. Kirby, 'Wavelength-dependent fading of artists' pigments', cited in note 4.
9. The National Gallery's instructions on 'Lighting for Photography and Television' are based on the guidelines produced by the French National Committee of ICOM (ICOM Committee for Conservation – Lighting Group, *ICOM News*, December 1969, pp. 61–5) and modified by Garry Thomson: see G. Thomson, *The Museum Environment*, 2nd edn, London 1986, pp. 47–8.
10. See note 6.
11. See note 4.
12. G. Rosetti, [*Plictho de larte de tentori*] *The Plictho of Gioanventura Rosetti*, trs. S. M. Edelstein and H. C. Borghetty, Cambridge, Mass., and London 1969 (includes facsimile of 1st edn, Venice 1548), pp. 60, 153.
13. G. Rosetti, cited in note 12, pp. 17, 107.
14. H. Schweppe, *Handbuch der Naturfarbstoffe: Vorkommen: Vervendum; Nachweis*, Landsberg/Lech 1992, pp. 341, 390; J. S. Mills and R. White, *The Organic Chemistry of Museum Objects*, 2nd edn, London 1994, p. 148.