The use of sodium lamps for low-intensity laboratory safelighting for optical dating

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Abstract *The choice of laboratory illumination for use with optical dating samples involves a compromise between minimising the unwanted bleaching of light-sensitive signals while providing sufficient visibility to allow efficient and safe workplace practice. Described here is a laboratory safelight fulfilling these requirements. The safelight module consists of a low-pressure sodium vapour lamp enclosed within a filtered and shuttered housing, and provides low-intensity (< 1 $\mu W/cm^2$) yellow-orange light, predominantly from the well-known 589.0 and 589.6 nm sodium D-lines.*

Introduction

Following the introduction by Hütt et al. (1988) of a novel means of optical dating utilising infrared-stimulated luminescence (IRSL) from feldspar minerals, a practical source of illumination was required to provide laboratory lighting that would not significantly bleach near-IR and visible-light-sensitive dating signals. Hütt et al. (1988) had avoided near-IR and the longer-wavelengths of visible light and instead utilised low-intensity blue light for safelighting, based on a consideration of the visual response of the human eye to low light levels.

However, studies of the bleaching response of feldspar luminescence (subsequently reported in Spooner 1993, 1994b) showed that even at low-intensities the blue wavelengths are effective at bleaching OSL and IRSL, and earlier work on the TL bleach spectra of feldspar (Krønborg, 1983) had revealed that short-wavelength (<550nm) visible light bleached the 330°C TL of K-feldspar, and Spooner et al. (1988) showed similar behaviour for quartz. An ideal laboratory safelight should be conveniently usable with these minerals, hence a source deficient in both blue/UV and IR was sought. Previous recipes for laboratory safelighting, by Sutton and Zimmerman (1978), Jensen and Barbetti (1979), Spooner and Prescott (1986), Smith (1988) and Galloway and Napier (1991), were variations on filter-wrapped or coloured fluorescent tubes, which emit strongly in the blue and also produce some very-low-visibility emissions > 700nm. An alternative means of isolating an orange-red waveband (Lamothe 1995), rejects both shorter and longer offband wavelengths using IR-absorbing "detector trimmer" glass in conjunction with Lee 106 red filter, passing red light of approximately 600-650 nm.

However, although orange-red/red wavelengths are not greatly less effective in bleaching the feldspar luminescence than yellow-orange, they are less visible to the observer. Indeed, the human eye is a critical factor in safelight selection, responding strongly to both light intensity and colour and exhibiting two intensity-dependent regimes - photopic (cone-dominated) and scotopic (rod-dominated) vision. The transition from photopic to scotopic vision (the Purkinje effect) occurs at about 1 lumen/m^2, which for 555 nm light corresponds to about 150 nW/cm^2, but the threshold varies between people, not least by reason of age. Photopic vision has peak response at 555 nm, with 10% points at about 475 nm and 650nm, and 1% points at about 430 nm and 685 nm, with the limits for visibility lying at about 390 nm and 780 nm.

The photopic response curve is approximately symmetric, and as the efficiency of bleaching both quartz and feldspar by visible light decreases monotonically with increasing wavelength, safelight wavelengths should be chosen from the long-wavelength wing of the photopic curve as these bleach less for equivalent visibility than the same optical power flux of shorter wavelength illumination. The scotopic response curve has similar form to the photopic, but shifted approximately 50 nm to shorter wavelengths, hence below the photopic-scotopic transition red is even less visible relative to green-orange than it is in the photopic regime. Consequently red wavelengths are not ideal if very low illumination intensities are sought, and the waveband range of 555-630 nm (corresponding to 100%-25% relative to peak photopic response) represents the optimal compromise between visibility and minimal bleaching.

Choice of light source took into account the ease of selection of this desired waveband, and factors such as cost, general availability, operator safety, reliability and lifetime. Low-pressure sodium lamps fulfil the practical criteria and emit the majority of their radiant energy in the sodium D doublet at 589.0 and 589.6 nm, with only weak emissions in the UV/blue or near-IR wavebands, and so place minimal demands on optical filtering to remove the strongly-bleaching near-IR and UV/blue light (high-pressure sodium lamps, commonly used for example as highway lighting, emit significantly in both these wavebands and so are undesirable in this application).

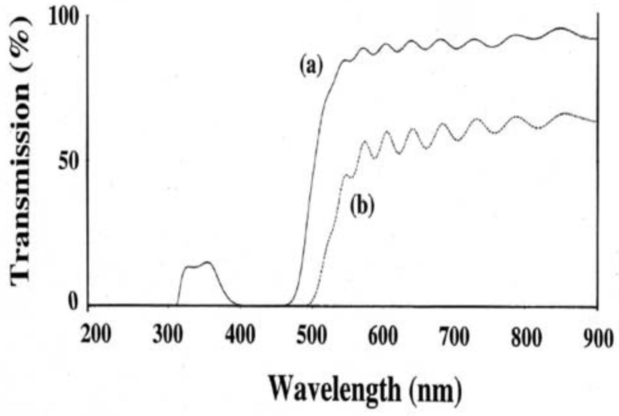

Figure 1. *The transmission spectra of (a) one layer of Lee 101 yellow filter and (b) a 5-layer stack of the same. The relatively strong attenuation of the stacked filter layers is inconsequential for visibility, as the unfiltered lamp output greatly exceeds the required illumination intensity. The distinctive "ripple" at wavelengths > 550 nm is not a measurement artefact.*

The sodium lamp illumination module

The original module, developed in 1989 by the authors at the Research Laboratory for Archaeology and the History of Art (RLAHA), Oxford, comprises one Osram MW 18W Super SOX low-pressure sodium lamp mounted within a sealed and shuttered housing of 360 mm length and 200 mm diameter. The housing is manufactured from opaque PVC tube and sealed at both ends (the ANU version is smaller for bench-top convenience, at 310 mm length and 160 mm diameter) and has the advantage of portability compared to fluorescent light fixtures.

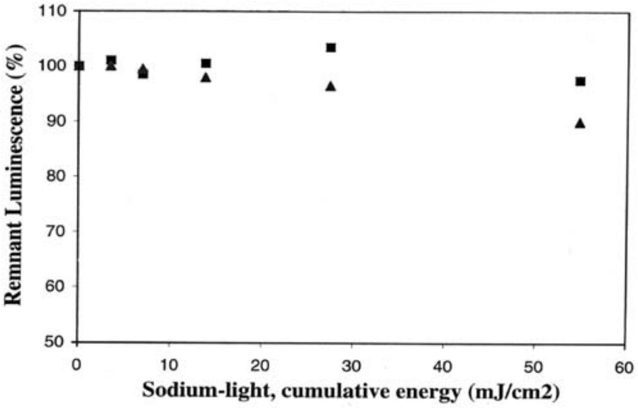

Figure 2. *Bleaching of IRSL and OSL by illumination from a sodium lamp module delivering ≈ 950 nW/cm^2 to the sample, plotted as percentage of initial intensity. Full abscissa scale corresponds to ≈ 200 hours exposure to practical working-levels of sodium light. Triangles represent IRSL from Achenheim loess. Stimulation was by 853.0 Δ 82.4 nm IR from a filtered xenon lamp set (Spooner and Questiaux, 1989), and detected by an EMI 9635QA optically filtered by one 2 mm Schott BG 39 filter, passing approximately 450-600 nm. Squares represent OSL from Chaperon Rouge quartz, with UV emissions detected following short exposures to 514.5 nm light*

Illumination emanates from one 50 x 85 mm window, elliptical in shape and of 36 cm^2 area, screened with five layers of Lee 101 yellow plastic filter. The clear aperture of the window is adjusted by a sliding opaque shutter (conveniently produced from similar tubing as used for the housing). The transmission spectra of these filters were measured at RLAHA, Oxford, and pass < 1 part in 10^4 for wavelengths < 450nm, per layer of filter plastic (50% pass at approximately 500 nm), effectively blocking the weak shorter-wavelength sodium emission lines. The transmission spectrum of 5 stacked layers of Lee 101 yellow filter is shown in Figure 1. Although the Lee 101 filter has high IR transmissivity, IR emissions from low-pressure sodium lamps are insignificant and can be safely ignored.

Two steps are taken to improve the uniformity of illumination: a layer of Lee 216 white diffusion filter is added to the stacked Lee 101 filters to disperse the emitted beam, and then indirect illumination is obtained by targeting the module window towards the ceiling or a light-coloured wall to effectively produce a large-area dim source (so aiding retention of dark adaptation by eliminating the window as a bright "spot" source in the direct line of vision). The diffuse reflected light when the shutter is fully opened is ample for "housekeeping"; activities requiring unshielded exposure of samples are performed with the module window 90% closed by the shutter.

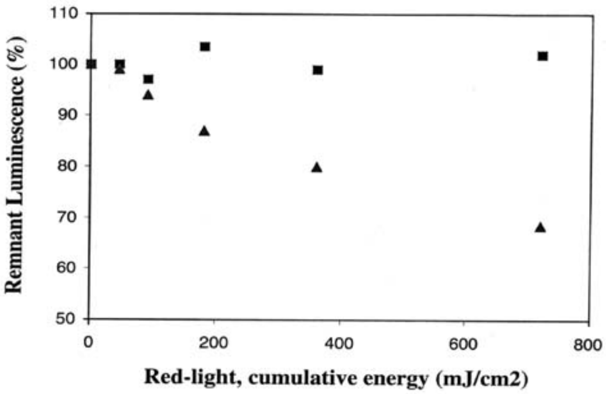

Figure 3. *Bleaching of IRSL and OSL by red illumination from fluorescent tubes wrapped with 6 layers of Lee 106 primary red, delivering ≈ 12.5 μW/cm^2. Triangles represent IRSL from Achenheim loess and squares OSL from Chaperon Rouge quartz. Measurement conditions as in caption for Figure 2. Full abscissa scale corresponds to ≈ 200 hours exposure to practical working-levels of light.*

Performance Tests

Bleaching of OSL and IRSL was assessed in two ways. Firstly, by measurement of the optical power under typical darkroom conditions followed by calculation of acceptable exposure times using bleach response data from Spooner et al. (1988) for quartz, and Godfrey-Smith et al. (1988) and later Spooner (1993, 1994a,b) for quartz and feldspar. Secondly, samples were exposed to cumulative doses of safelight and the bleaching of OSL and IRSL monitored by short exposures to IR and 514.5 nm light. We did not investigate the bleaching of TL on the assumption that the more optically-sensitive OSL and IRSL signals would better reveal any deleterious effects of the safelights.

An alternative laboratory illumination in use at RLAHA and ANU consists of 40W fluorescent light tubes wrapped in 6 layers of Lee primary red 106 filter; these were also tested (see Figure 3).

(1) Power measurements

Optical powers at typical safelight intensities were measured at various locations in the darkroom, using a large-area silicon photodiode (Radio Spares cat. # 303-674) calibrated by means of a spectrally-insensitive pyroelectric radiometer (Molectron Corporation, model PR-20). The minimum intensity for practical work under sodium lamp illumination was measured to be ≈ 2 nW/cm^2 and a comfortably-bright working level with samples exposed, obtained with the shutter 90% closed, was ≈ 100 nW/cm^2. When the shutter was fully opened the light intensity was typically ≤ 1 μW/cm^2, depending on module aspect and location in the laboratory.

Typical red-light intensities from fluorescent tubes wrapped in 6 layers of Lee 106 ranged between ≈ 0.2 μW/cm^2 and ≈ 15 μW/cm^2

Bleaching after various exposure durations at these intensities can be estimated from Figures 2 and 3, or calculated from the data sets of Spooner (1993, 1994a,b). Spooner (1994a) showed that ≈ 150 mJ/cm^2 of 589.4 Δ 8.9 nm light was required for a 5% reduction of the 514.5nm-stimulated OSL from quartz., equivalent to about 420 hours of exposure at the comfortable sodium light intensity of 100 nW/cm^2, indicating about 1% bleaching of the fast component per 3-4 days exposure at this intensity. The extent to which this slow bleaching rate gives a margin of safety to normal laboratory procedures is self-evident.

Similar measurements were reported in Spooner (1993, 1994b) for bleaching IRSL from a microcline feldspar: 43mJ/cm^2 of 589.4 Δ 8.9 nm light was required to reduce the IRSL from this sample by 10%, corresponding to about 5 days exposure to illumination of intensity 100nW/cm^2, ie., about 2%/day. Green (514.5nm) stimulated OSL from this same sample resisted bleaching by 589.4 Δ 8.9 nm light more strongly, a 10% reduction requiring 170mJ/cm^2, which corresponds to ≈ 20 days safelight exposure at ≈ 0.5%/day decay rate.

It was concluded that the time required for significant bleaching (>2%) of either quartz or feldspar OSL or IRSL at practical illumination powers far exceeds cumulative exposure times accrued in typical laboratory practice.

(2) Bleaching of quartz OSL and feldspar OSL and IRSL

The sodium lamp was tested with window fully open, and the optical power at the sample was measured as 30/10 photodiode-meter units, corresponding to ≈ 950 nW/cm^2. Red-light exposures were made underneath a red-filtered fluorescent tube at an illumination intensity of 12.5 μW/cm^2 (for comparison, we consider ≈ 100 nW/cm^2 sodium light and ≈ 1 μW/cm^2 red light to be practical laboratory illumination levels).

These experiments utilised OSL from HF-acid-etched 90-125 μm quartz (Chaperon Rouge, Morocco, sample 724g, Rhodes, 1990), and both OSL and IRSL from 4-11 μm polymineral fine-grains extracted from two loess samples (Achenheim, Germany, sample T1, Questiaux 1990, and Val Sorda, Italy, sample VS1, Accorsi et al., 1990). Natural luminescence only was used; results are shown in Figures 2 and 3.

Depletion of OSL from the Chaperon Rouge quartz was not clearly produced by either red or sodium light exposures. However, under red light the Achenheim fine-grains exhibited depletion rates of ≈ 4 %/day for IRSL, compared to ≈ 1.2 %/day under sodium lamp illumination, these rates being calculated for the above-nominated practical laboratory illumination levels for the respective lights.

Exposure of the second loess sample, VS1 from Val Sorda, Italy, to the sodium lamp module with the shutter 90% closed gave a 10% reduction of IRSL after the equivalent of 28 days exposure. This IRSL (N + beta + preheat) bleaching rate is slower than, but still in reasonable accord with, that of the Achenheim loess and comparable to those above and reported by Spooner (1993, 1994a,b).

It was concluded that red light results in a slower decay rate per unit energy, but as significantly higher powers of red light are required for similar visibility, for "real-time" exposures the sodium light is safer. While recognising that "practical" light intensity is subjective, given the individuality of eyesight, we estimate that full scale on Figures 2, 3 corresponds to 200 hours exposure at practical darkroom illumination levels.

Discussion and Conclusions

When used at very low-intensities (< 100 nW/cm^2), the 500-650 nm waveband is safe for feldspar luminescence, but only the longer portion of that waveband is advisable for use with quartz. The precise illumination intensity chosen will depend on the worker's eyesight and the nature of the procedure, noting that "pitch black" is ≈ 0.01 nW/cm^2 at 550nm, and the minimum practical intensity for seeing was measured to be ≈ 1 nW/cm^2, and a comfortable working intensity was ≈ 100 nW/cm^2.

A related issue is that of bleaching at elevated temperatures, such as when samples are removed from preheat ovens. These results, considered with Spooner (1993, 1994a) and Bailey (1998), indicate that increased bleaching efficiency at raised temperatures does not present problems at typical laboratory illumination intensities.

We note that neither the sodium lamp module nor the red light produced unambiguous depletions of 514.5 nm-stimulated OSL even over substantial exposure durations, and conclude that in practice both red-filter-wrapped fluorescent tubes and sodium lamp modules provide "safe" light conditions for preparation and manipulation of green-light-stimulated OSL samples at typical illumination intensities and durations. However, the situation appears different when red illumination is used with samples intended for IRSL analysis. Here the sodium lamp illumination is preferred on account of lesser bleaching, as well as for providing greater visual contrast, giving better visibility of objects and "sharper" perception of shadows. The principal drawback is the requirement of a 10-15 minute warm-up period for the lamp to attain full luminosity, and as this is much of the typical duration required for dark-adaptation, this delay is readily accommodated in laboratory routine.

In summary, the justification for the use of 589 nm sodium light is that the human eye sees it more efficiently and with greater visual comfort than it does red light, hence significantly less intense sodium light gives viable laboratory illumination. Practical benefits of the sodium lamp modules include easily adjustable illumination intensity, low energy consumption, and reliable, low-hazard, low-cost long-life lamps. The quality of illumination afforded by these modules, in terms of improved contrast and visual "comfort", exceeds that of red-filter-wrapped fluorescent tubes and from the perspective of many individuals, particularly older people, given that red-acuity diminishes with increasing age, they offer a means of continued and comfortable work under OSL/IRSL-safelight conditions.

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