What is the best Lamp for Gemmology?

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1. What is meant by 'white'?

It is reasonable to think that all a gemmologist needs is a light that is constant and white. Unfortunately, human vision is easily bamboozled: there is an infinite number of ways of producing the sensation of pure white. The human eye cannot see all possible spectral colours separately. Although the number of different colour receptors is still unclear, there seem to be only three types. Their peak sensitivities are in the blue, the green and the orange parts of the spectrum, but their sensitivities to wavelength are so broad that any monochromatic wavelength is likely to stimulate all three (see Adler's Physiology of the Eye). Distinguishing colours must therefore involve computation in the brain and neuronal parts of the retina, starting with the degree of excitation of each type of receptor. A mixture of only three spectrally pure lights , or even two, of appropriate relative intensities, is sufficient to produce a sensation of white. I have a laser which emits 488nm (blue) and 568nm (yellow). The beam looks reasonably white (though it is improved in whiteness by adding a small amount of red at 647nm). This acceptance of quite unnatural mixtures as white may well be connected with a natural adaptation to changes in the colour of daylight. As any photographer knows, evening sunlight is orange, but the human visual system compensates for this, so the sunlight continues to look white until dusk. Film has no brain and shows the truth: transparencies taken late in the day have a yellow/orange cast. Gemmologists have long recognised that direct sunlight, and particularly evening light is no good for assessing gems. Even though such light looks white, it may be severely blue-deficient . This presumably means that a white diamond and a yellow one (which differ only in their ability to transmit blue light) would appear to match, if compared in the evening.

Our own colour sensations are clearly useless when trying to decide on a standard white lamp. We have to rely on instruments, particularly spectrometers. The purpose of this short article is to emphasise that we also have to study the absorption spectra of the gems that are to be illuminated.

2. Emission spectra of various lamps (Figure1).

I present here a number of emission spectra in the range 350-900nm, recorded with a USB4000 spectrometer manufactured by Ocean Optics Inc. This is a pocket-size box which plugs into a computer. I passed the light into the spectrometer via a single silica optical fibre, adjusting the distance between the fibre input end and the lamp until the recorded peaks were of comparable height for different lamps. Because of this, the spectra convey no information about the relative brightness of the lamps.These spectra are the raw data, not corrected for the fact that the silicon detector is much more sensitive around 800nm than at other wavelengths. The peaks at the blue end and in the infra-red above 800nm are likely to be underestimated. Also, the baseline was set at an arbitrary position near, but not at, zero intensity.

The simplest spectrum is that of a **tungsten halogen lamp**. This is a broad smooth curve with a peak in the red at about 610nm**. Daylight** peaks around 550nm (yellow/green). This was recorded near noon from a cloudy sky in Cambridge UK in summer. Note that the daylight spectrum shows prominent dips (clusters of Fraunhofer lines) such as that at 760nm, which is due to absorption by oxygen in the earth's atmosphere. Comparison of the two spectra shows that daylight is quite a bit bluer than the tungsten halogen light but the spectra are basically similar. They correspond well to the spectra predicted by the physical theory of so-called *black bodies* heated to different absolute temperatures. The entire spectrum can be predicted from theory if the temperature of the body is known, and the bluer the light the higher the temperature. Lights of this type can be defined by a single number, the 'colour temperature', which corresponds to the absolute temperature of the filament in the case of an incandescent lamp. For diamond grading, a colour temperature of 5500Kelvin has been specified. This is rather high for filament bulbs, but was achieved by enclosing the filament in a blue glass envelope, to create the first type of 'daylight bulb'.

Gemmologists have turned in modern times to fluorescent tubes and light-emitting diodes (LEDs). These sources have an attractive longevity, as well as low power consumption. Colour temperature is meaningless with these, since they do not obey black body rules: their spectra are not smooth curves. To express their general blueness or redness, an 'equivalent colour temperature' is sometimes used, but it is not helpful in describing the complex nature of their spectra, which determine their interaction with gem spectra.

I tested several compact fluorescent tube lamps. A Wotan DULUX S, Ectron and **EcoLamp** had almost identical spectra. All the emission was in distinct lines, including mercury lines at 405, 436 (violet) and 546nm (green) and a europium line at 611nm (red). A large ceiling tube light, marked **'Sylvania'** which gave a slightly warmer light, had a prominent broad peak surrounding the europium line but was otherwise similar to the compact lights. Another fluorescent lamp, the **OTT lamp**, which is advertised in the USA as a 'full-spectrum' source for craft work including gemmology, has a spectrum quite similar to that of the other fluorescent tubes, but with a continuum in the form of a long low peak, maximum at about 490nm and stretching through to approximately 700nm.

A **white LED** (Luxeon) had a totally different spectrum, consisting of a sharp peak at 450nm (blue) and a much broader one at 560nm, with a width at half-maximum height of approximately 130nm.

3. Effects of these lights on the appearance of a gem material (Figure 2)

Some of those lights emit in wavebands which are comparable in width to some of the specific absorption bands in gem materials. In that case, the light transmitted by each gem depends critically on the precise spectral position of the absorption bands relative to the peaks of irradiance. In this situation, colour temperature becomes irrelevant.

In order to test possible effects of different lamps on colour, I have photographed a gem cut from a synthetic gem material marketed as 'Tourmalike' by faceting suppliers. I have been unable to find the composition of this material, but it is clear from the spectrum that neodymium contributes to much, but not all of the absorption. Fig.2 shows the images obtained with a Nikon DS-2 microscope camera with a 40mm Zeiss Luminar lens, in which the gem was moved aside and the white balance was reset for each type of illumination, using a white paper background, before the image was recorded. The exposure time was varied to try to achieve a similar background brightness in each case. All the tests, except the one done in daylight, were conducted in a windowless room without any source but the test lamp. Reflections from nearby objects were minimised by surrounding the gem with a bell-shaped frosted glass diffuser and holding the light source close to the diffuser.

The gem colour recorded by the camera corresponded well to that seen by eye: strongly pink in tungsten halogen light, pink in daylight, green in all the standard fluorescent lights, dull yellowish green with the OTT and, surprisingly, brownish and dark with the LED lamps.

4. Accounting for these colour changes by observing the alteration in each spectrum caused by the stone.

The spectra of the light transmitted from each type of lamp through the ‘Tourmalike’ specimen are shown in Fig 3 . This was done by placing a 10mm thick cuboid of ‘Tourmalike’ between the fibre and the source. I think it is possible, with this data, to explain the colour changes of Tourmalike in the different lights. Basically, the europium red line is the principal cause of the changes: it is just too short to be transmitted by the Tourmalike, and so the common fluorescent tube light is reduced to the green line and the material therefore looks green. The Sylvania, OTT and LED lamps have enough red above 611nm to provide both green and some red transmission through the stone, and so it looks green plus red, which is greenish yellow or olive/brown, depending on the brightness and relative proportions of green and red. The blue peak of the LED lamp, which is very high, is reduced to even less than the red and green, hence the dark brownish appearance in the LED lamp.
A tungsten lamp provides plenty of long-wavelength visible red, but the removal of some green and blue by absorption in the gem gives it a red bias, which makes the stone look pink. The same is true for daylight.

5. Conclusions and Discussion

It may be objected that Tourmalike is an misleading choice of test material, since it shows the most dramatic colour changes known of all gem materials. However, neodymium is found in many species of coloured stones, so these effects may occur to a lesser degree in many varieties of gemstones. While colour changes with ambient light have seldom, to my knowledge, been recorded for diamond, diamonds often do have lines or bands in their absorption spectra (see *The Spectroscope and Gemmology*, pp 214-222) and the exceedingly subtle colour gradations that the grader seeks to separate may perhaps be affected by the choice of light source in the way demonstrated here. For example, if the dip in the irradiance spectrum of an LED at 480nm happened to correspond to an absorption band in a yellowish diamond, a falsely high grade might be reported.

If this proves to be so, difficult and prolonged studies with the various types of diamond will be necessary before any new lamp, particularly of the fluorescent or LED type can be accepted. LEDs are still in a rapid state of development, so any assessment would need to be reviewed.
It would seem safer to stick with a tungsten halogen lamp with a blue envelope for the moment. Such lamps are available, apparently quite cheaply, from Solux Inc. (Rochester, N.Y.). It will probably be necessary to run them at a measured voltage and measure the colour temperature periodically to check for aging effects.

The present recordings show violet emission by the fluorescent tubes, particularly the 436nm mercury line. There has been much discussion of whether such short-wavelength lines might influence perceived colour by inducing blue fluorescence. It would be interesting to test this by interposing a filter that removed only the short-wave light from the tube spectrum.

For photography, the new compact fluorescent replacements for incandescent bulbs seem to be an excellent choice, provided their colour-changing properties are taken into account. As described in my previous article in Stonechat, a bell-shaped diffuser surrounding the gem reduces the dynamic range of the image in a useful way, but some variegation in the illumination structure created by attaching opaque tape to the diffuser allows dispersion colours or ‘fire’ to be photographed with these sources as easily as with tungsten halogen lamps. The strange colour induced in Tourmalike by LEDs is worrying: the appearance of each type of gem needs to be checked with these sources. In other respects, including their small size, low power consumption and the ease with which they can be made into a shadowless ring-light, these sources are very attractive.

As a hobby gemmologist, I have been fortunate in being able to acquire a recording spectrometer, but I do not as yet have a standardised irradiance source to use for correction of my raw spectra (the calibrated source is expensive). Nor have I yet been able to test any lamp specifically recommended for diamond grading. Perhaps this short report will stimulate others to repeat, improve and extend these measurements.

I thank John Harris (GemLab UK) for drawing my attention to spectra on the website of one manufacturer of fluorescent tube lamps (http://www.lifelite.de) showing a promising result with a larger continuum than I have observed here.

Lamps tested

OTT light true color 13W Type PL operated in the UK by the use of a step-down transformer.
Sylvania Standard F58W/135 T8 Made in Germany
Halogen bulb 12v 20W G4 socket.
Ecolamp Philex 9W 19364 R (purchased in a supermarket).
Luxeon White LED type LXK2-PW14-U00

References

Adler's Physiology of the Eye (1992) IX edn. ed. W.M.Hart Jr. Mosby Year-Book Inc. St. Louis.

The Spectroscope and Gemmology B.Anderson and J. Payne ed. R.K.Mitchell (1998) N.A.G. Press London.

FIGURES

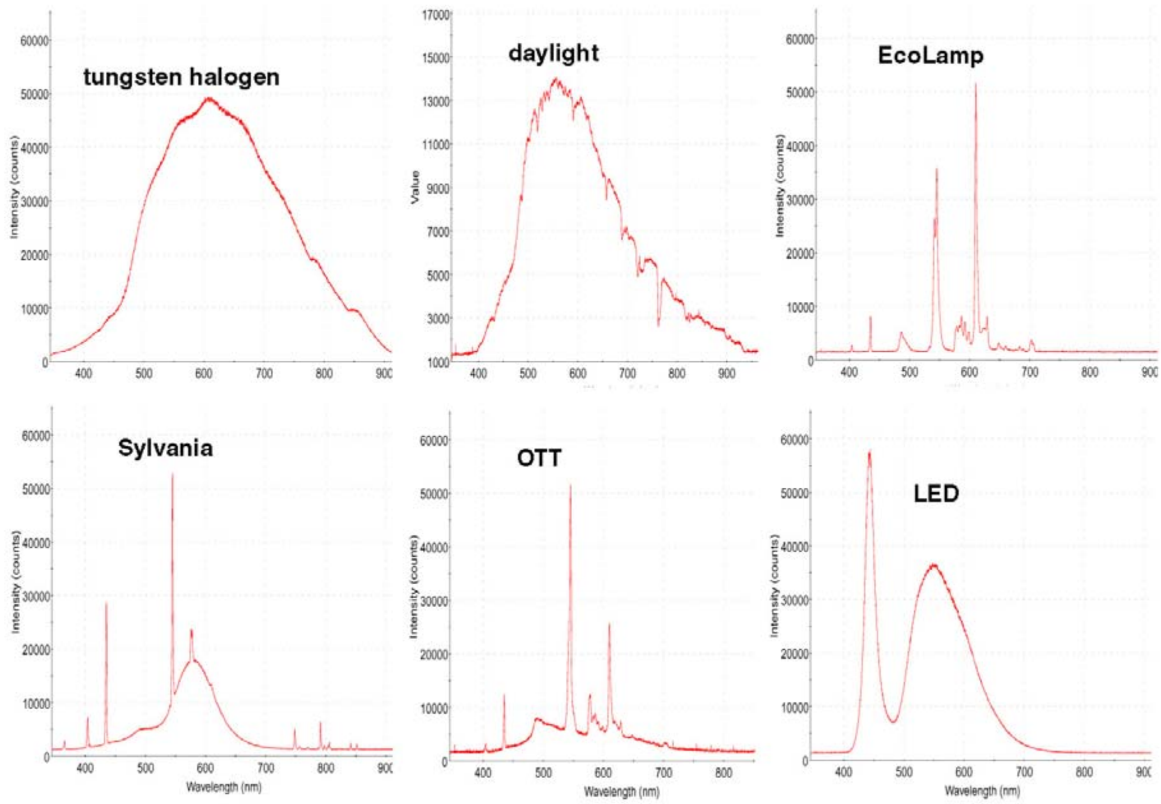

FIGURE 1 Spectra of a number of light sources

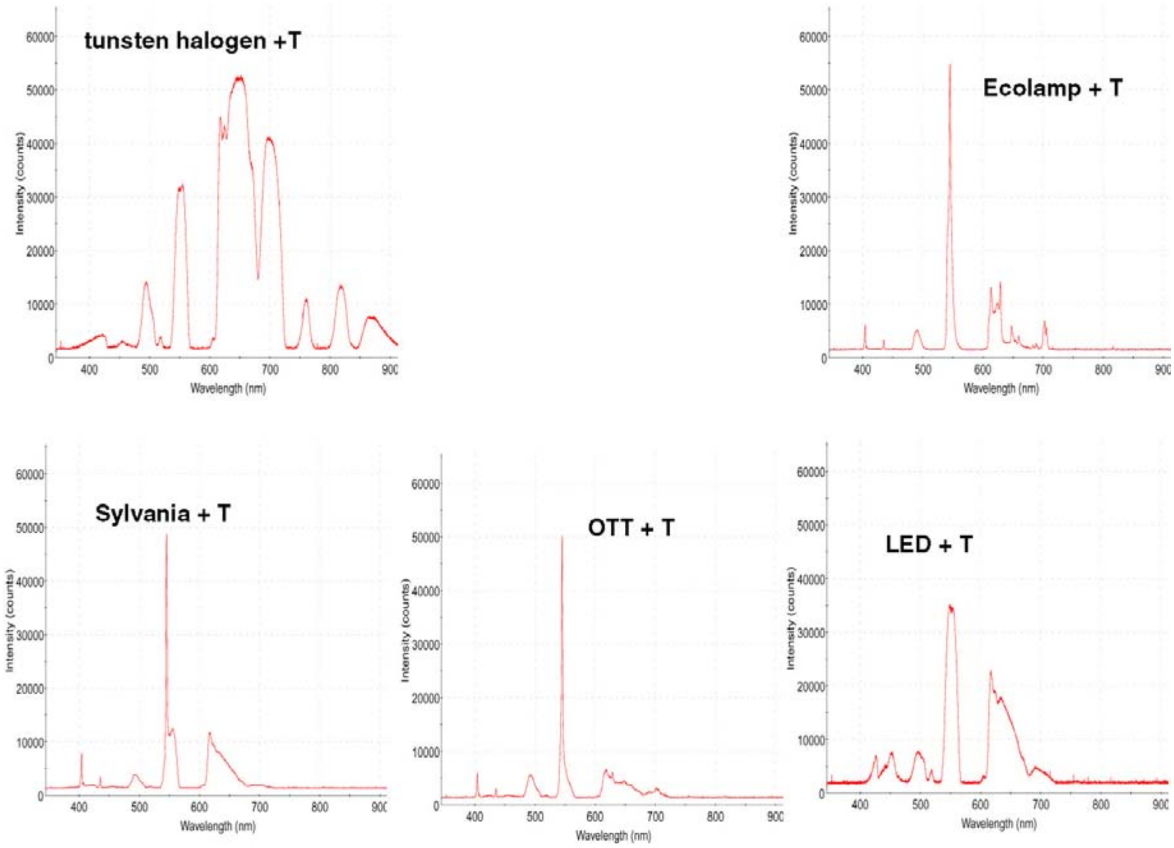

FIGURE 2 Spectra of light sources after passage through ‘Tourmalike’

FIGURE 3 Tourmalike gem (14mm square) photographed with various types of illumination, resetting camera white balance before each photograph.