Topic 18: Optical radiation: infrared, ultraviolet and visible light

This Topic (dated 2015) is an updated version of Topic 18, which appeared in the 3rd edition of *Topics in Safety* (ASE, 2001). There have been changes in legislation on optical radiation, and changes to the classification of lasers and LEDs since the 3rd edition. Laser devices and light emitting devices have become available in higher optical outputs and greater selection of spectral outputs since 2001.

18.1 Assessing the risks

The risks from optical radiation are now regulated by *The Control of Artificial Optical Radiation at Work Regulations*, with the aim of protecting workers from the dangers of these radiations. The Regulations set exposure limit values (ELVs). The ELV applies to people not to the source. ‘Optical radiation’ is defined in these regulations as electromagnetic radiation in the wavelength range between 100 nm and 1 mm and therefore includes the non-visible ultraviolet radiation (UVR) and infrared radiation (IRR) parts of the electromagnetic spectrum. If you purchase an optical source from a reputable supplier then you should expect it to come with information on the spectral output and any safety precautions required when using the source.

Employers are required to make sure employees (and others affected by their work) are not exposed to artificial optical radiation exceeding the relevant exposure limit value. Assessing the exposures from optical sources can be problematic because it is dependent on several factors, for example, the spectrum emitted, the directionality of the emissions, and how far away people are from the source. If the manufacturer of an optical source has not given information on the spectral and optical power output, the assessment may require a spectrophotometer to measure the spectral emissions, something a school is unlikely to have.

18.2 Visible-light lasers

Visible light is in the range of wavelengths from 400 to 700 nm. Low-power, visible-light lasers sold for teaching purposes are an excellent way of demonstrating various wave effects because the beam is monochromatic, bright and coherent, with low divergence over the distances used in school laboratories. Many of the optical demonstrations traditionally done using conventional light sources are far more easily and convincingly done with a laser, including those involving geometrical optics. Diffraction through a single slit, a grating, or around an edge, and the resulting interference patterns can all be shown relatively easily. Refraction at boundaries is easily shown; for a glass-water boundary a few drops of skimmed milk added to water aids visibility of the beam. An ‘optical fibre’ made up from a polythene tube filled with water with a few drops of skimmed milk shows multiple internal reflections when a laser beam enters one end. (Discard the milky water after use and wash the apparatus.)

However, lasers can cause permanent eye damage if used incorrectly. The risk depends on the optical power output, wavelength, size of the image formed on the retina and duration of exposure. (Since there are no pain receptors in the retina, an injury may pass unnoticed until a blind spot is identified in the person's field of vision.) Lasers sold in the UK should be marked with their classification based on the international standard IEC 60825. See Table 1. Class 1 is the least hazardous, Class 4 the most. The USA had a different classification system using Roman numerals instead of numbers: Class I, II, IIa, IIIa, IIIb and IV. This system is still used in their product safety regulations. There isn't an exact correspondence between the IEC and this USA system, but a USA Class II is equivalent to IEC Class 2.

Table 1. IEC laser classification system

Classification	Description of Class
Class 1 laser	A low-power laser (emitting visible or non-visible light) that is unlikely to cause harm under reasonably foreseeable conditions of use.
Class 1M laser	As Class 1. May be hazardous if the beam is viewed through an optical system.
Class 1C laser	A laser intended for treatment of the skin or internal tissue close to the skin where the product is designed to be safe for the eye.
Class 2 laser	These lasers emit only visible light and are limited to a maximum output of 1 mW. They are bright enough to cause dazzle. A deliberate attempt to stare into the beam might produce retinal damage but the period for safe viewing, 0.25 s, is about the same as the natural aversion response.
Class 2M laser	As Class 2. May be hazardous if the beam is viewed through an optical system.
Class 3R laser	Class 3R visible light lasers are limited to 5 mW. The risk of injury is greater than for the lower classes; the natural aversion response is not adequate for protection.
Class 3B laser	Direct beam viewing from these lasers will damage the eyes. Viewing diffuse reflections is not harmful.
Class 4 laser	Direct beam viewing from these lasers will damage the eyes. Reflections are hazardous. The beam can burn material.

(You may see lasers marked Class 3A, this is a classification under an old version of IEC 60825 which is now obsolete and should not be used on new lasers.)

We advise that schools buy only visible-light lasers with a classification of either Class 1 or Class 2; no other Class (not even 1M or 2M) should be purchased. A laser of unknown or doubtful classification should never be used in school science. For practical activities, use a Class 1 or 2 laser device designed for the practical work, preferably with an integrated automatic power control. CLEAPSS and SSERC are useful sources of advice on this. Be cautious when considering using a laser pointer for practical activities – see section 18.2.1.

When using Class 2 lasers, they must be placed and used in a way that intrabeam viewing is extremely unlikely. ('Intrabeam viewing' is where the laser beam is incident on the eye, either directly from the laser or by reflection from a shiny surface.) Care is needed in setting up optical apparatus to prevent beam reflections going into the eyes of the person setting up the equipment, and the eyes of those observing the practical work. There is no reason why students under close supervision should not be allowed to work with Class 2 lasers. Where practicable, keep background lighting at a high level to ensure that the pupil of the eye is very small, although some demonstrations are not best viewed in this way, which means the risk may be greater. Mounting and clamping the laser securely avoids sudden changes in direction of the beam.

The natural aversion responses of blinking, which take about 0.25 s, and turning the head away should give adequate protection from accidental intrabeam viewing of the beam from a Class 2 laser. The aversion response is most effective in the visible red to green wavelengths, but less effective in the deeper red wavelength or the far blue because of the reduced sensitivity of the eye, and ineffective where the laser radiation is ultraviolet or infrared. Any exposure that exceeds the natural aversion response may require medical attention, especially as the person exposed may not be aware of any loss of vision until some time after the event. Medical staff treating the patient may require exact details of the incident and type of laser.

In the 1970s, the government advised wearing laser goggles for all school-based work. This advice had to be withdrawn after a few years because there is no need for laser goggles if school-based work adheres to the advice given in this Topic. Although laser goggles are essential for high-power laser work, they are of no use with low-power lasers because, when the goggles are worn, the demonstrator can neither see the beam clearly nor see where it may be going.

18.2.1 Laser pointers

Semiconductor-type lasers have become cheap to the extent that they are used in presentation pointers (usually referred to as laser pointers) and in novelty items such as key rings, costing only a few pounds. It is tempting to consider using these as lasers for practical work, rather than more-expensive laser units from school science suppliers. However, be cautious. There is good evidence that the power rating stated on laser pointers available to the public is often wrong. Public Health England has examined laser pointers and found that some marked Class 2 were actually Class 3B[1]. At Class 3B, your natural aversion response (blinking and turning away) is unlikely to provide adequate protection from eye injury. There have been similar reports from USA and Australia[2]. These reports concluded that a worryingly high percentage of laser pointers had wrongly-stated power outputs, some with power outputs around the 100 mW level. These high-power devices (which often look very similar to safer Class 2 pointers) can cause immediate, severe eye injury. Additionally, some cheap green lasers emitted unacceptably high levels of infrared radiation in the beam[3]; part of the cheapness is achieved by omitting infrared filters from the device. The output from a cheap green laser may seem low-power, but the infrared, which is invisible, may cause injury to the eye if viewed directly.

We do not advocate a ban on laser pointers from use in science practicals. The problem isn't about laser pointers as such. It is about the availability of poor-quality equipment that is attractive initially because of the cheap price. See section 18.2.3.

18.2.2 DIY and second-hand lasers

Laser modules that have an internal regulated power supply so that the laser always operates as Class 2 can be used. The module needs to be firmly mounted so that it can be positioned and fixed in place during practical work. Buy modules from reputable suppliers – see section 18.2.3. Only use modules that have automatic regulation. Do not use unregulated devices because slight variations in power supply affect the laser output considerably, possibly producing dangerously high output levels.

---

1 PHE (2014) *Guidance. Laser radiation: safety advice*. Available online at www.gov.uk/government/publications/laser-radiation-safety-advice/laser-radiation-safety-advice (accessed January 2015).

2 Hadler J, Tobares E, Dowell M (2013) *Random Testing Reveals Excessive Power in Commercial Laser Pointers*. J. Laser Appl 25: 032007. Also, Wheatley, T (2013) *Laser pointer prohibition: improving safety or driving misclassification*. Proceedings of the International Laser Safety Conference 2013. pp. 48-54.

3 Galang J, et al (2010) *A Green Laser Pointer Hazard*. NIST Technical Note 1668.

Good-quality solid-state lasers are inexpensive so there is no justification in removing old lasers from equipment for reuse. If you acquire a second-hand laser, you must be confident of its classification, and it should be tested for electrical safety before use. Note that gas lasers often have internal extremely high-voltage circuits.

18.2.3 Buying laser devices

There are many lasers, laser pointers and other laser devices from suppliers with incorrect classifications. These can be very dangerous. Lasers from dubious suppliers, marked as Class 2, have been found by CLEAPSS and SSERC to have a much higher output, over 10 mW. Some advertisements boast high-power modules that would make them Class 4 lasers; such powerful devices could easily produce severe and permanent eye damage and have no justification for use in school science.

If you want to buy a laser (including laser pointers or other laser devices), use a supplier with whom you have recourse if you have concerns, and who has a reputation to protect. Avoid auction and classified advert sites (such as eBay and Gumtree) and market stalls. Also be wary of online retailers who use third-party sellers. Read the sales information carefully. Look for a CE mark; this is a claim that the laser pointer meets the minimum relevant European safety standards, so the class should be indicated according to EN 60825 (see Table 1). Where advertising states the device is CE marked, but the classification in the advertising or on the laser picture is a USA code (Class II, Class IIIa, Class IIIb, etc), you should be sceptical that the device meets European standards.

Avoid buying laser devices in the following circumstances.

- There is no CE mark stated, or on the device itself.
- The classification code is not stated as Class 1 or Class 2. (Saying “less than 1 mW” is not enough.)
- There is a claimed equivalent safe classification code such as USA Class IIIa, Class IIIb, or even just Class III.
- The advertising uses adjectives such as *powerful, ultra-bright, super-bright, military-grade*, even if the output is claimed to be no more than 1 mW.
- There is poor wording in the advertising, eg specifying the laser pointer as “less than 1 MW” (which means megawatt rather than the intended milliwatt, a clear error).
- The advertising features performance terms such as *‘burning’, ‘balloon popping’, ’ten mile distance*’.
- The price seems just too good to be true, considering the specification advertised.

You need to be prudent in your choice of suppliers so that you can be reasonably confident that what you buy meets the specification you require.

18.3 Ultraviolet radiation lasers and infrared radiation lasers

These are far more hazardous than visible-light lasers of the same power level because the beams are invisible (or barely visible) to the eye. There may be no warning of stray reflections. Class 1 devices (IEC 60825-1:2007) are unlikely to cause harm under reasonably foreseeable conditions of use (this assumes the device has been classified correctly). Any other Class should be avoided in school science; if the use can be justified, obtain specific advice from

CLEAPSS or SSERC, and a university Laser Protection Officer. Note that the classification Class 2 cannot be applied to ultraviolet lasers because it relates to visible-light lasers only.

18.4 Light-emitting diodes (LEDs)

Standard LEDs that emit relatively low visible light levels, tens of millicandela (mcd), pose no optical risk to the eye. High-brightness LED products, often described as 'ultrabright' or 'superluminescent' should be treated as one would treat a laser. LED products emitting high-intensity infrared radiation or ultraviolet radiation are not recommended for school science use.

LEDs are classified to indicate the level of hazard, but with a different classification system to lasers. The classification is defined by British Standard BS EN 62471 according to the intended use of the LED. There are 4 classes, called groups:

- Exempt group - no photobiological hazard.
- Risk Group 1 - low-risk, no photobiological hazard under normal behavioural limitations.
- Risk Group 2 - moderate-risk, protection by aversion response to bright light or thermal discomfort.
- Risk Group 3 - high-risk, hazardous even for momentary exposure.

A classification given by a supplier or manufacturer may be too conservative if you use the device in a different way or mode than it was designed for, or if you use additional optical components to increase the light intensity. Manufacturers of equipment using LEDs in risk groups 1 to 3 should label the device accordingly with product information, eg a warning label, but this doesn’t always happen.

For Risk Group 2, you will need to use further safety precautions to avoid exceeding exposure limits. Risk Group 3 means the device is an eye hazard even for momentary exposure - these devices should not be used in school science.

The data sheet for a visible-light LED component usually states the luminous intensity, in millicandela (mcd) at a specified forward current. Assuming the LED is not operated above this specified forward current, you are unlikely to exceed exposure limit values from a single red, yellow or green LED rated at less than 5000 mcd luminous intensity, with sensible use, although the LED may cause dazzle and after-images if stared at. Keep in mind that the light output from an LED will increase if the current goes above the specified level in the data sheet. For blue and violet LEDs, the same can be said if the luminous intensity does not exceed 50 mcd. (The luminous intensity for blue light is much lower because the candela is a unit of perceived brightness and the eye is less sensitive to blue light than green. Blue light also has a greater photochemical retinal hazard weighting than the light of longer wavelength.) Note that white LEDs emit some blue light. If you need to use LEDs with greater luminous intensity, set up the apparatus so that the LED is not viewed directly, keeping in mind the polar intensity (wide beam or narrow beam output).

Avoid specialised very high intensity LEDs, LED modules and arrays because these can give high exposures likely to exceed the exposure limit values.

18.5 Infrared radiation (IRR)

A common source of artificially-produced IRR is the beam from the remote-control units for TV and audio systems. These present little hazard and can show simple reflection - a task not beyond the agility of the most hardened couch potato? IRR lamps and heaters are more commonly used in the laboratory either as driers or to show the heating properties of the radiation.

Short-term exposure to IRR may cause the skin to redden or produce a blister if the skin burns. Long-term exposure of the eyes to IRR is associated with cataract formation rather than retinal damage. IRR lamps and heaters will quickly char paper and set it on fire. They can also damage bench tops and the insulation on electrical cables. Keep a clear area around these IRR sources when in use. Laboratory IRR sources are only intended for use over short time periods. If used for extended time periods, because of their intensity, it would be best to warn those present to limit skin exposure within, say, one metre of the source and not to view the source directly at all within this distance.

Mains-powered carbon filament and glass or silica envelope IRR heaters are those most commonly used in laboratories. However, the use of mains heaters with exposed elements, which were common in schools, presents too high a risk of electric shock no matter how fine the protective mesh and is considered too hazardous by the HSE. This includes use by staff for demonstration purposes. Such heaters should have been withdrawn from use years ago and replaced by low-voltage models, or the glass or silica-sheathed element versions, but old ones do turn up occasionally. Keep in mind glass or silica envelopes may fracture explosively if splashed with water when at working temperature. Carbon filament lamps are vacuum devices and so they may implode if the glass envelope fails. Normal working with lamps, including carbon filament lamps, does not usually warrant wearing eye protection, for example connecting low-voltage lamps to investigate parallel and series circuits. However, use eye protection if working close to filament lamps in circumstances where breakage and flying debris into the face is plausible.

High-intensity LED devices emitting infrared radiation are not recommended for school science use.

18.5.1 Detection of IRR by skin

Using the cheek as an IRR detector should be avoided with younger students or in cases where students may come into contact with the radiant device. In such cases the back of the hand is preferred but, even so, the susceptibility and sensitivity of young skin varies considerably and great care is needed to avoid burns. The trigeminal nerves in the cheeks are highly sensitive to IRR and older students may usefully experience this fact by momentary exposure to IRR under close supervision.

18.6 Ultraviolet radiation (UVR)

Many fluorescent effects require UVR. Some photochemical reactions require it for initiation. It may induce mutations in microorganisms and it can be used to produce ozone. UVR is needed in practical work on photo-electrons and the Planck constant as well as work on plant growth and germicidal sterilisation.

The Sun is by far the major source of our personal exposure. Many school employers advise staff to minimise the risk to children on school trips and when working out of doors by the use of sun-screen lotions as well as covering up exposed skin.

18.6.1 UVR Classification and limits

Ultraviolet radiation is usefully classified by wavelength into 3 bands:

UVA 315-400 nm.
UVB 280-315 nm.
UVC 100-280 nm.

Visible blue light has a wavelength range of approximately 400-500 nm. 'Black lights' are mercury discharge tubes fitted with filters which block visible light, UVB and UVC, so that only UVA is emitted.

There are legal limits of exposure set by the regulations. The risk factors from UVC and UVB are greater than for UVA. If the ultraviolet source only emits in the UVA band, the maximum radiant exposure is 10^4 J m^{-2} over an 8-hour period. If the source emits UVR other than just in the UVA band, the legal limit for the effective radiant exposure is 30 J m^{-2} (spectrally weighted) over an 8-hour period.

18.6.2 UVR - Risks and control measures

Excessive short-term exposure to ultraviolet causes skin reddening and eye damage such as photokeratitis and conjunctivitis. Prolonged exposure of the eyes to UVR may cause painful inflammation lasting for days and will require medical attention. Excessive eye exposure can also cause cataracts.

Long-term exposure to ultraviolet light is linked to skin cancer. The International Commission for Non-Ionising Radiation Protection (ICNIRP) considers that UVA, UVB and UVC are all implicated as cancer risk factors - the risks from UVB and UVC being higher – but there remains some uncertainty regarding UVA.

Some people have photosensitivity. There are many causes; it can arise because of the medication the person is taking. People with photosensitivity to ultraviolet light can experience painful skin and eye damage even from low levels of ultraviolet light. Students with this condition may have to work in another room when practical work with UV is taking place in the laboratory.

In the laboratory, skin exposure to all kinds of UVR should be kept to a minimum with experimental arrangements designed to make it so. The eyes should be protected from all laboratory sources. Although UVB is considerably more damaging than UVA, many sources produce both emission types, so avoiding eye and skin exposure is by far the best protection. Four mm thick float glass (float glass is the type commonly used to glaze windows) does not transmit UVB and so makes an effective shield for UVB sources. It is ineffective as a UVA filter, so shouldn't be used with a high-output UVA source. As with visible light, UVR reflected from a shiny surface is hazardous, so equipment should be set up to avoid UVR being reflected towards observers.

Ozone is formed around UVR lamps and the gas may cause headaches and irritate the eyes and upper respiratory tract. Ventilation should be adequate to disperse the gas.

18.6.3 Some sources

Table 2 on the next page gives examples of UVR sources used in schools and typical safety precautions.

Electric arcs emit UVR. High-current electric arcs struck between electrodes, for example carbon rods, emit prolific wide-spectrum UVR and are not recommended as UVR sources.

Table 2. Some UVR sources and typical precautions

UVR source	Spectral output and other notes.	Typical precautions
Hand-held security lamps	Fluorescent tube rated at less than 10 W. The security lamp emits mainly in the UVA spectrum. Useful for demonstrating fluorescence. Do not mistake 'sterilising wands' for security lamps. Sterilising wands are far more hazardous, emitting UVC.	Keep fingers away from the front of the lamp; avoid looking directly at the lamp.
Hand-held UVC 'sterilising wand'	Fluorescent tube rated at less than 10 W. The fluorescent lamp emits mainly in the UVC spectrum at 254 nm. Can be used as a substitute for TUV-6 lamps for photoelectric effect demonstration.	Choose a battery-operated unit with a UV lamp rating not more than 6 W. Keep fingers away from the front of the lamp. Do not allow the beam to be viewed directly, or by reflection from shiny surfaces, or be directed onto the skin. Label the wand clearly to make sure it is a not mistaken for a UVA source. If the UV lamp emits no visible light, it needs an auxiliary light to show when it is on.
Halogen lamps (for example, car headlamps)	Broad spectrum output, from infrared to ultraviolet. Lamps usually have a filter to attenuate the UVR. There is usually insufficient UVB to be effective in demonstrating the photoelectric effect.	Not recommended as UV sources. Avoid using lamps with no UVR filter. Be aware of the IRR emissions as it can cause skin reddening if the lamp is too close to the skin.
TUV-6 lamp low pressure mercury discharge lamp and cylinder shield	Lamp rating is typically 6 W. The optical output has a sharply-defined peak at 253.7 nm, in the UVC spectrum. This type of source is needed for showing the photoelectric effect.	The exposure limit value will be exceeded in a short time close to the lamp. The lamp must be used with the shield so that the UVR output is directional and not incident on skin or eyes of observers. The use of this source should be restricted to teacher demonstration and post-16 students under supervision.
UV-LED components	These come in many types. Single UV-LEDs are available at a few tens of mW optical power with a narrow band in the near-UVR region peaking at about 390 to 400 nm. (There are also UV-LED arrays that emit higher optical powers with spectral output peaking at 360 nm. UV-LEDs are becoming available that emit well into the UVB and UVC band. These are not recommended; it is difficult to justify using these in school science.)	The single low-power near-UVR LEDs are relatively low risk, but nevertheless you should avoid looking directly at the light or bringing them close to the eye. It would be a good idea to mount the LED into an opaque plastic shield to prevent direct viewing. Note that LEDs are often very directional. The exposure limit value from UV-LEDs emitting in the UVB or UVC band are likely to be exceeded in a very short time. Shielding precautions will be needed similar to that for other high-output UVB and UVC sources, eg the TUV-6 lamp.
Bench ultraviolet transilluminators	Used to view DNA or RNA that has been separated by electrophoresis through a gel. The spectral output of the transilluminator needs to correspond to the stain that has been used. If UVB and UVC transilluminators are viewed without the filter, the exposure limit value could be exceeded in a short time.	Use transilluminators with interlocked filters so that there is very little risk of looking directly at the unfiltered source. Consider using stains that fluoresce under UVA or blue light. See *Topic 16*.
Sunlight		See 18.7 and 18.8.

18.7 Viewing the Sun, and solar eclipses

Since there are no pain receptors in the retina, those viewing the Sun without protection will initially be unaware of any retinal damage. Much has been written about how to view the Sun especially at times of a solar eclipse. The safest view of the Sun is by an image projected on to a screen.

The eclipse can be viewed directly through eclipse viewers that have a special dense solar filter. Make sure the eclipse viewers are CE marked and meet current British and European standards. Check them carefully just before use for any signs of damage to the filter. Eclipse viewers usually come with instructions – follow them carefully. Eclipse viewers have a shelf-life, do not use old ones. Do not use home-made viewing filters - they are most unlikely to be effective at reducing the sunlight to a safe level.

Never view the Sun or an eclipse of the Sun directly through an optical instrument, no matter how dense a filter is used.

18.8 Other hazardous light sources

Apart from the hazards of sunlight detailed above, there is a particular hazard associated with the use of daylight reflected by the mirror of a microscope. If the mirror should catch the Sun, a ray of intense sunlight could pass through the eye to the retina and permanent damage may result. For this reason, microscopes utilising daylight for illumination must never be sited on a bench near a window where direct sunlight may enter.

Avoid standing in front of a data projector other than momentarily, and do not look directly into the projector beam.

Flickering light, eg from a stroboscope, can cause photo-epilepsy, although this is rare. See chapter 12 in *Safeguards in the School Laboratory*.