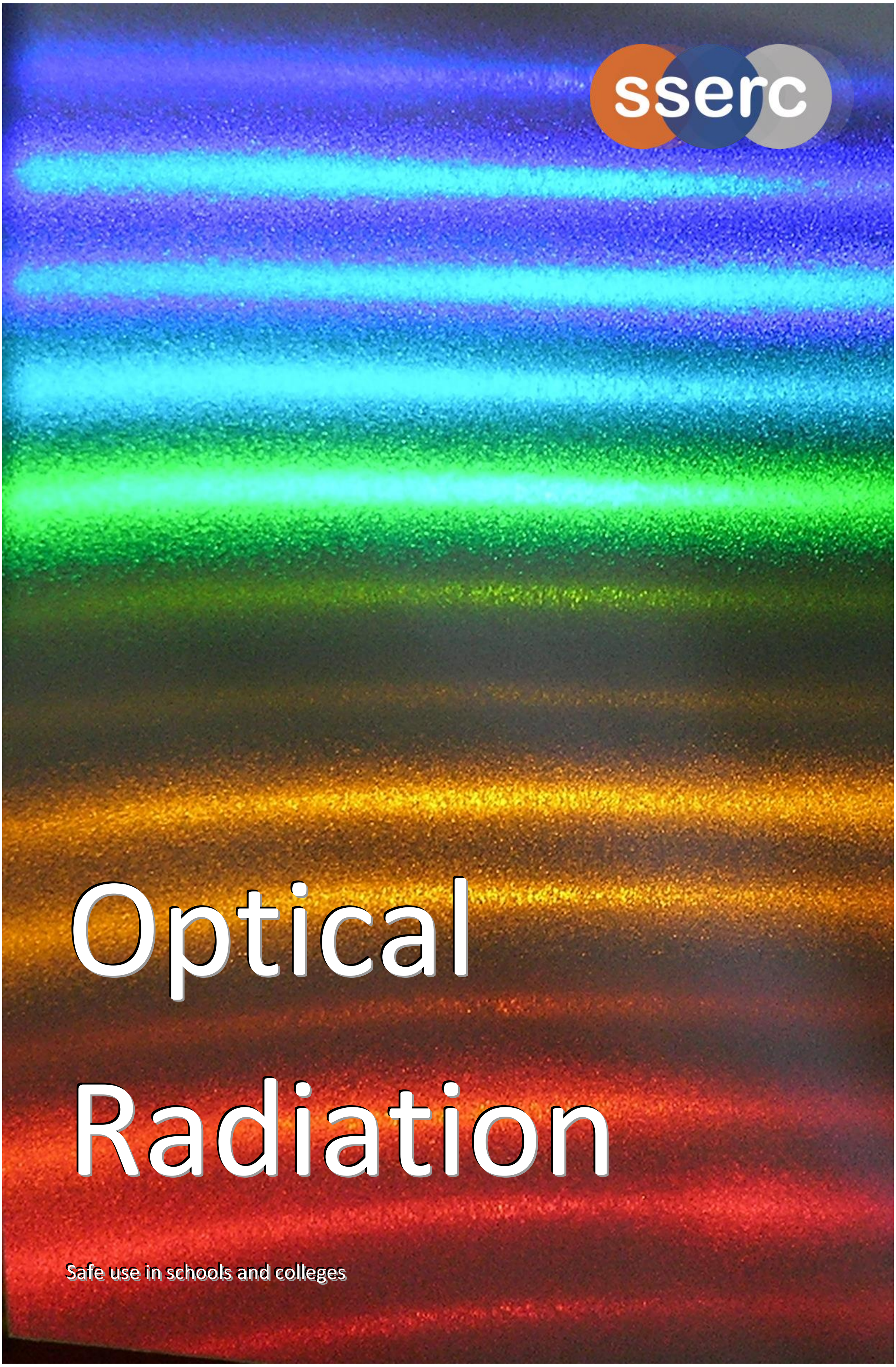

Optical Radiation

Safe use in schools and colleges

Contents

1 Introduction

1.1 Why write about optical radiation?

There is an increasing variety of sources of optical radiation in use in schools. From many, the risk of harm is trivial. Safe lamps are listed in sections 4 and 5. Others do require special control measures and sometimes the hazards are not obvious, blue LEDs being a good example. This document aims to give the information necessary to help you to risk-assess an activity involving optical radiation and decide on appropriate control measures. It should help schools and colleges to comply with *DIRECTIVE 2006/25/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 April 2006 on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation)*. Whilst the guide is chiefly designed to provide information on sources of optical radiation in school science and technology classes, advice is also given on school-wide sources such as LCD projectors.

1.2 What is optical radiation?

Optical radiation is the part of the electromagnetic spectrum that includes ultraviolet, visible light and infrared. The diagram below, which is not to scale, shows the full electromagnetic spectrum, in order of increasing wavelength.

Gamma rays	X rays	Ultraviolet	Visible light	Infrared	Microwaves	Television and radio

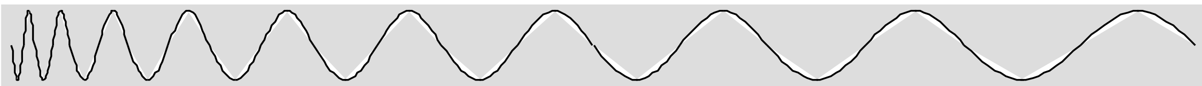

Figure 1 – Electromagnetic Spectrum

We will concern ourselves with radiation between 200 nanometres (nm) and 1400 nm, though strictly speaking, optical radiation covers a larger wavelength range than this.

1.3 Visible radiation

Visible radiation is any radiation that can directly cause a visual sensation. This is not precisely defined in terms of wavelength since the visual sensation will depend on the sensitivity of the viewer and the radiant power reaching the retina. The lower limit is generally taken to be between 360 nm and 400 nm, the upper between 760 nm and 830 nm.

1.4 Ultraviolet (UV) radiation

This is optical radiation with a shorter wavelength than visible radiation. It is divided into three bands:

UV-A, from 315 nm to 400 nm (note that radiation between 380 nm and 400 nm is considered visible);

UV-B, from 280 nm to 315 nm;

UV-C, from 100 nm to 280 nm. (Note that radiation below 180 nm is vacuum UV and is strongly absorbed by the oxygen in the air.)

1.5 Infrared (IR) radiation

Infrared radiation is optical radiation with a longer wavelength than visible radiation. Whilst it is also commonly subdivided into IR-A, B and C, we will only be concerned with IR-A, from 780 nm to 1400 nm.

2 What are the biological effects of optical radiation?

2.1 Main effects

Biological effect	Part of body affected	Effect and symptoms	Spectral range causing effect	Comments
Photokeratitis	Cornea	Feeling of “sand in the eye”. Sudden, violent, involuntary contraction of eye muscles. Some clouding of vision. Reaction delayed by 4 to 12 hours following exposure. Tends to clear in 24 to 48 hours, except for extremely severe exposures.	UV, principally 200 – 320 nm, peaking at 270 nm.	Sometimes known as arc eye as arc welding apparatus produces UV light.
Photoretinitis (Blue-light retinal injury)	Retina	Loss of vision where light was imaged on retina. Loss of vision may be permanent, though some recovery is noted in cases of sun-gazing.	Visible, principally 400 – 500 nm	Aversion reflex provides a level of protection.
Ultraviolet cataract	Lens	Clouding of vision due to opacification of lens. Generally delayed by 4 or more hours. Sometimes clears within days but may be permanent.	UV-A and UV-B	
Ultraviolet erythema	Skin	“Sunburn”, reddening of skin where exposed. Reaction generally delayed by 4 to 12 hours. Clears within 24 to 48 hours, except for severe exposures.	UV	UV-A and UV-B are likely causes of skin cancer. There is a high risk of harm with UV-C. A combination of UV-A, B and C is a known carcinogen.

Note: a headache can be an indicator of over exposure to UV radiation.

Table 1: biological effects of optical radiation

2.2 Other effects

Infrared radiation may cause thermal cataracts. Visible and infrared radiation can also cause retinal thermal injury. Neither of these effects is likely to occur in a school situation. Quoting BS EN 62471:2008, Section A.4.9 on thermal retinal injury:

"Virtually no lamp is capable of causing this type of injury....Natural aversion response normally limits exposure to preclude injury."

When the HPA assessed Lumiled LEDs, they found that none of them posed a thermal retinal injury hazard. However, the natural aversion response, described below, is not triggered by IR, so we did assess IR LEDs for thermal retinal injury hazards.

2.3 Photosensitivity

Some people have abnormal responses to UV radiation. This is called photosensitivity and may be caused by genetic or metabolic abnormalities or by contact with certain drugs or chemicals. Pupils or students with this condition may have to sit in another room when work with UV is taking place in their classroom.

2.4 UV and cataract surgery – a warning

It should be noted that people who are missing the lens of an eye due to cataract surgery are at a higher risk of suffering **retinal** damage when working with a UV source as the lens would normally absorb a substantial amount of UV.

2.5 Aversion response

The body has several defence mechanisms that attempt to protect the eye from damage from visible light. The pupil contracts and can reduce retinal irradiance by a factor of around 30, there may be blinking and the head may turn away involuntarily. On average, this takes 0.25 s to happen. The aversion reflex is not universal and children may choose to override it. For example, they may deliberately stare at a light source.

The aversion response only happens for radiation that is detectable by the eye. It offers no protection against UV or IR as there is no visual stimulus.

2.6 Photosensitive epilepsy

This is covered in SSERC Bulletin 210. A small section of the population is susceptible to epileptic fits induced by flickering optical sources including stroboscopes, TVs, computers and disco lights. Some control measures are suggested in the article.

3 School sources of optical radiation

Here we deal with artificial sources of optical radiation. The sun is of course a source of UV, visible and IR radiation. It should not be looked at directly and, if pupils and teachers are working outside, the risk of erythema should be assessed.

Only hazards associated with optical radiation will be discussed. For example, when discharge tubes are mentioned, the hazards due to their use with EHT power supplies will not be covered.

3.1 Ray boxes

Tungsten lamps are generally considered to be safe. It would be possible to exceed exposure limits if a pupil was to stare into a ray box from a close distance. However, the aversion reflex would cause the pupil to blink or look away. Any pupil or student seen to be staring into the beam of a ray box should be warned. For LED and laser ray boxes, see the relevant sections on LEDs and lasers.

3.2 Discharge tubes (spectral lamps)

Our first assessment was carried out on a sodium lamp as shown left. We assessed the photochemical hazard (sometimes called the "blue light" hazard). This takes into account the irradiance of the source at different wavelengths, applies a weighting factor for each wavelength and takes into account the solid angle subtended by the source. From this, we calculate a biologically effective radiance, which is independent of viewing distance. This is then compared with the exposure limit. If the exposure limit is exceeded, a maximum exposure time is then calculated.

Figure 2 – Sodium lamp and power supply

The weighting factor for the principal yellow sodium lines (at around 595 nm) is small. The exposure limits were not exceeded. We then considered a scenario where a tube gave out all its light at a wavelength with the largest possible weighting factor (435 – 440 nm, blue light). Again, the exposure limit was not exceeded.

Note –for **mercury** discharge tubes that are designed to emit UV radiation, see section 3.5.2 on UV lamps.

3.3 LEDs

LEDs in use in schools include high power Lumileds, medium power LEDs used in electronics work and as indicators, UV LEDs and IR LEDs. There are two hazards from LEDs – the photochemical retinal hazard and the thermal retinal hazard. Both are biologically weighted. When we assess the biological effect of ionising radiation we apply a weighting factor that is greater for alpha radiation than for gamma. Similarly, when assessing the above hazards from visible light, we apply weighting factors that are related to wavelength.

3.3.1 LED Photochemical hazard

The exposure limit is expressed in terms of biologically effective radiance (not irradiance). This quantity is independent of viewing distance, so if an LED is viewed along the optical axis, the maximum permissible exposure time is the same for any distance. Note that this hazard is cumulative over an 8 hour period. The figures in table 2 below represent the sum of all exposures in an 8 hour period. For example, the blue LED time would be exceeded by two 20 second exposures within an eight hour period.

The figures in table 2 come from the Health Protection Agency. They agree with measurements we have made at SSERC. They are for 1 W Lumiled LEDs. These are much more powerful than the small indicator LEDs found on ICT equipment and in electronics boards such as Alpha kit.

1 W Lumiled LED	Maximum permissible exposure time
Blue	25 – 30 seconds
Green	~20 minutes
Red	~6 hours
White	10 – 12 minutes

Table 2: maximum exposure times for Lumiled LEDs

Red, green and white LEDs do not present a real risk because extended viewing of the beam directly along the optical axis over a period of minutes is unlikely, due to the discomfort from a very bright light. The maximum exposure time for blue is much shorter. The probability of photochemical injury to the eye is still small. This is partly because we find it uncomfortable to view a very bright light. These LEDs emit light in a relatively narrow angular cone. The risk decreases rapidly with off-axis viewing.

Users should be advised not to stare directly at the LED. If blue Lumileds are not part of some stable device, for example commercial colour-mixing apparatus, they should be clamped.

3.3.2 LED Thermal retinal hazard

Unlike photochemical limits, the exposure limits for this hazard depend on the viewing distance. Once again, a weighted value is found and a time to reach the exposure limit is calculated. If the exposure limit is not reached in 10 s, there is no risk of thermal retinal injury. At 100 mm, taken to be the closest accessible distance, the maximum permissible exposure time for the 1 W blue Lumiled LED was found to be 81 s. Again, blue light has a higher weighting factor than red or green. As this worst-case scenario exceeds 10 seconds, none of the LEDs presents a thermal injury risk to the retina.

3.3.3 IR LEDs

We assessed a GaAs infrared LED for the thermal retinal hazard. This LED gives a very low visual stimulus. Indeed, it is impossible to tell that it is on just by looking at it. This means that it will not trigger the aversion reflex. Unlike the photochemical hazard, the thermal retinal hazard increases as you get nearer to a source. We calculated the biologically weighted irradiance at distances from 50 mm to 1000 mm. It was well within limits at all distances and can thus be considered to be safe.

For advice on using UV LEDs, see section 3.5.4 on UV LED sources.

3.4 LCD projectors

These are considered safe provided that the user does not stare into the beam. Pupils and teachers standing in front of projectors should position themselves so that this does not happen.

3.5 UV Sources

Ultraviolet light is used in schools to show fluorescence, for experiments with sun creams, for investigations in biology and for the photoelectric effect in physics. Not all lamps emit UV with a sufficiently high frequency to cause photoelectric emission from zinc.

UV light can also be used to sterilise surfaces, but this practice is not currently widespread in schools.

3.5.1 Hand Held UV Lamp

These are sometimes called black lights. They are not suitable for showing the photoelectric effect with zinc as the frequency of light that they emit is too low. The spectrograph below is typical of one of these lamps:

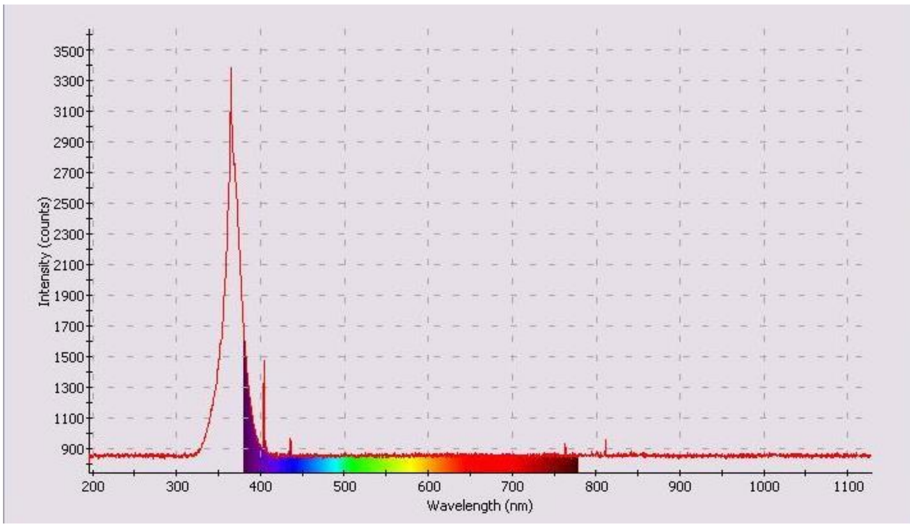

Figure 3- Spectrograph of light from a hand held UV lamp

Most of the radiation is UVA, hence there are hazards to the eye and skin. We measured the emissions from the lamp and conclude that exposure limits are unlikely to be breached in a school laboratory provided that:

- Users avoid looking directly at the lamp;
- Users do not hold or carry the lamp with their hands or fingers across the tube when the lamp is on (see photograph below);
- Users avoid irradiating their skin where possible.

Figure 4- Do not carry a UV lamp this way if it is switched on

Best practice would be to use a light box, that is, a box designed to enclose the lamp tube and the item to be irradiated. A suitable design is described in Bulletin 208. If it is not practicable to use a light box, hold the lamp in a clamp rather than the fingers.

13.5.2 Sterilising Wand

Note that the lamps we are describing here are available from high street shops to show up "invisible ink" security markings. They should not be confused with lamps sold for sterilising surfaces (right). The latter emit UV-C radiation. Whilst this makes them suitable for photoelectric effect experiments, the control measures have to be much more stringent. A mask should be made for the lamp that allows only the required amount of radiation out. The lamp must not be looked at directly, nor should the skin be irradiated.

Figure 5- UV sterilising wand

3.5.3 Philips TUV-6 lamp

This low pressure mercury tube lamp is used to demonstrate the photoelectric effect because it emits radiation at a high enough frequency to eject electrons from a clean zinc plate. The radiant power at its principal emission line of 253.7 nm is 0.085 W. This is UV-C. From manufacturer's data, we calculate a maximum exposure time of about an hour and a half for observers exposed to the radiation at a distance of 1 metre. For a hand irradiated while manipulating apparatus at 5 cm, the time is around 14 seconds. Note that the lamp is shielded, so it is unlikely that this exposure time will be exceeded. The UVA hazard is not present from this lamp.

Figure 6- Philips TUV-6 lamp

The lamp should therefore always be used in its shroud(right). Pupils should be told not to look directly at it. It is not suitable for pupil use other than by Advanced Higher students, who should be informed of the hazards and how to minimise the associated risks.

Figure 7- TUV-6 lamp used with shroud

3.5.4 UV LEDs

These come in a range of wavelengths. The advice for their use is as for the lamps described above, i.e. do not stare at them, do not irradiate the skin and be aware that the maximum exposure time to the skin for a UV-C LED will be of the order of seconds. Again, UV-C sources are for Advanced Higher student use only. For all other year groups, the teacher should demonstrate. These small sources are highly directional. A 35 mm film canister makes an effective shroud, but users should beware of reflections.

3.5.5 Car headlight bulbs

We have heard of some schools showing photoelectric emission using quartz-halogen car headlight bulbs. Our tests showed that a 55 W bulb gave out UV, but only a small amount was in the region that causes photoelectric emission from zinc. The Health Protection Agency has this to say about car headlamps, which they assessed in the context of car mechanics repairing vehicles:

Car lighting is not expected to present a UV hazard when the lamp's front glass or filters are intact. However, working with car lighting without the front glass or with damaged front glass may increase the risk of UV exposure. Working procedures should be adopted to avoid exposure from car lighting with damaged front glass or filters.

Therefore, you should not expose eyes or skin to a headlight bulb that is not protected by its glass cover. Since this glass would absorb the effective wavelengths of UV anyway, it is self-defeating. If you can get an electroscope to discharge using a headlight, it follows that it must be shrouded. A small aperture should be made so that the light is directed only at the zinc plate. As ever, beware of reflected UV.

3.6 Lasers

Lasers produce highly monochromatic light, as shown by the spectrograph below. The ones used in school are of low power, typically hundreds of times less powerful than a torch bulb, but laser power is concentrated over a very small area. It is this and the fact that the beam does not spread out significantly with distance that means we have to take certain precautions when working with them.

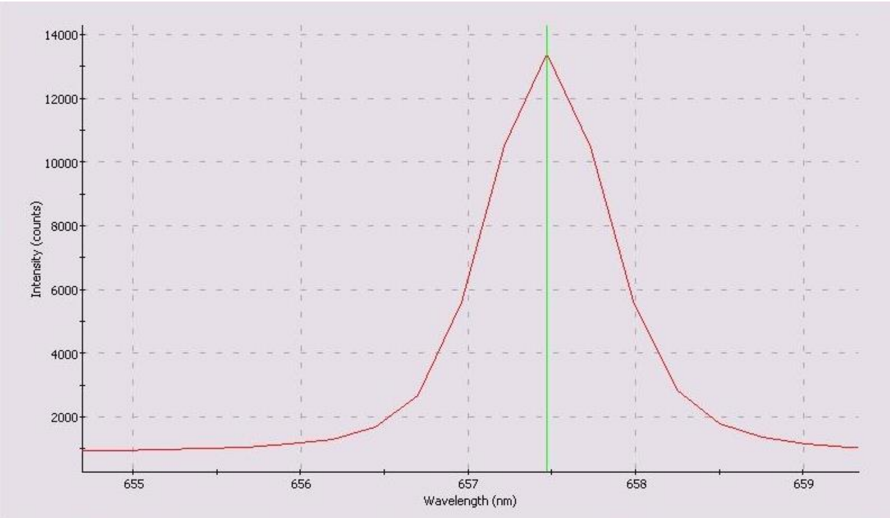

Figure 8- Spectrograph of laser source.

Lasers are classed according to their output power and the type of radiation that they emit. In 1996, we had said that certain lasers could be used by pupils in S3 and above. This was a relaxation of the complete ban on pupil use that was in place when lasers first appeared in classrooms in the 1960s. Much more is now known about lasers and their associated hazards. We therefore feel that we can permit their use in S1 and S2. Thus, all secondary pupils may work with lasers if the following rules are adhered to.

3.6.1 Rules for safe laser use

- The laser classification is either Class 1 or Class 2, but not Class 1M, 2M, 3R, 3B or 4.
- Work is supervised at all times.
- Pupils are made aware of the safety precautions they must take:
    - They must never stare into the beam;
    - The laser must not be pointed at another person.
- The laser is stable or clamped.
- The beam should be terminated by some sort of beam stop.

Why Class 2? Class 2 lasers emit only visible light and are rated at 1 mW or less. Our natural aversion response prevents us from becoming exposed accidentally to a harmful amount of laser radiation. America operated a similar classification system using Roman numerals. Whilst their Class II is equivalent to our IEC Class 2, there is not always a direct correspondence between the other ratings.

3.6.2 Laser pointers

Note that many laser pointers are unclassified. Their power output can vary significantly depending on the batteries fitted. Indeed, we have heard of some that are 35 times more powerful than they ought to be. Also, laser pointers may be picked up by pupils and waved around. A Class 2 laser pointer may be used by a teacher to highlight something on a board, but laser pointers should not be used for experiments.

3.6.3 Laser diode modules

Laser diode modules (LDMs) are a safer option than laser pointers. They can be clamped in a boss head. See SSERC Bulletin 229. The LDMs discussed in this article have automatic power control circuitry built in, so they do not exceed the appropriate power output.

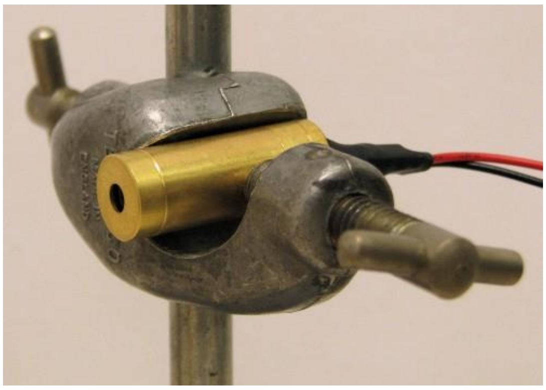

Figure 9- Clamped laser diode module

Some may still ask why we would want pupils to use a laser device. Whilst it is true that using a laser introduces an additional hazard compared to a conventional light source, the risk is small if it is operated properly. Using a laser ray box (right) removes the need for a blackout, reducing the risks associated with moving around a darkened room.

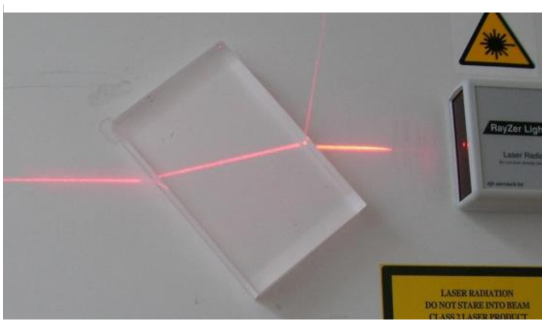

Figure 10- Refraction demonstrated using a laser ray box

4 Sources that are considered safe:

Ceiling mounted fluorescent lighting with diffusers over the lamps
Computer or similar display screen equipment
Ceiling mounted compact fluorescent lighting
Ceiling mounted tungsten halogen spotlighting
Tungsten lamp task lighting (including daylight spectrum bulbs)
Ceiling mounted tungsten lamps
Photocopiers
Indicator LEDs
Personal digital assistants, smartphones and tablets
Photographic flashlamps
Interactive whiteboard presentation equipment

5 Sources that are considered safe provided that they are used in a particular way

Source	**Notes on safe use**
Ceiling mounted fluorescent lighting without diffusers over the lamps	Safe at normal working illumination levels
Metal halide/high pressure mercury floodlighting	Safe if front cover glass intact and if not in line of sight.
Desktop projectors	Safe if beam not looked into
Low pressure UVA blacklight	Safe if not in line of sight.

6 Summary of control measures and guidance

The table below is designed to be a quick reference guide to precautions that should be taken using sources of optical radiation in schools. We suggest referring to the main text in all cases.

Source	Control measures	Guidance to users
Ray box (tungsten)		Teachers should look out for pupils deliberately staring at the bulb and warn them if they do so.
Discharge tube (spectral lamp) (This section does **not** apply to mercury tubes designed to emit UV)		Avoid staring at lamp, taking particular care if the lamp emits significant amounts of short wavelength (e.g. blue) light.
LED (This section does not apply to indicator LEDs which are considered safe)	Blue high power LEDs should be clamped or secured	Do not stare at the LED. Particularly important for short wavelength LEDs, e.g. blue Lumileds. Refer to main text for maximum exposure times (blue).
LCD projector		Do not stare into the beam.
UV-A lamp	Clamp lamps in place or use a light box.	Do not stare at the lamp. Avoid irradiating the skin.
UV-C lamp	Lamp must have a shroud.	Do not stare at the lamp. Do not irradiate the skin. Refer to main text for maximum exposure times.
Laser	Class 1 or 2 only, not 1M, 2M, 2A, 2C, 3R, 3B or 4. Clamp securely if using a small device e.g. a laser diode module. Use a beam stop.	Do not stare into the beam. Do not aim the beam at another person. Limits apply to laser pointers too. Do not use unclassified laser pointers. Do not use laser pointers for experiments.
Car headlight bulb	Use behind glass cover or with a shroud.	Gives out UV, so if not used with glass cover, avoid irradiating skin and do not look directly at it. If used with a glass cover, do not stare at the source.

BS EN *61010-2-092* Safety requirements for electrical equipment for measurement, control and laboratory use, Clause 12.3, currently in draft form, makes the following recommendations:

If the lamp system has a maximum permissible exposure time of less than two minutes, it shall have a warning marking that instructs the user never to look directly into the beam and not to direct it at anyone else.

Sources in school that meet this criterion include lasers and blue Lumiled LEDs.

7 Carrying out risk assessments

This document should help you risk assess activities that involve artificial optical radiation. Please contact SSERC for advice on sources that you feel are not fully covered here.

Our recommendations have been largely based on the work of others, in particular on that of the Health Protection Agency. Where possible, we have tried also to make our own measurements and perform calculations . Our spectrophotometer allowed us to measure the irradiance of LEDs and discharge tubes and we have calibrated UVA/B meters. Where measurement was not possible, we have used manufacturers' data. We cannot claim that our techniques are as rigorous as those employed by the HPA, so we have tried always to err on the side of caution.

Our aim has been to hone our techniques by comparing our values with those obtained by other agencies. Details of our methods can be found in the documents describing our treatment of UV lamps and blue LEDs.

8 References

BS EN 62471:2008 Photobiological safety of lamps and lamp systems

DIRECTIVE 2006/25/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 April 2006 on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation)

A Non-Binding Guide to the Artificial Optical Radiation Directive 2006/25/EC, Radiation Protection Division, Health Protection Agency

SSERC gratefully acknowledges the help given by Marina Khazova of the HPA Laser and Optical Radiation Dosimetry Group, particularly in the area of LED assessment.

9 Relevant SSERC Bulletin articles

There have been many articles about optical radiation in SSERC bulletins. The following ones complement rather than duplicate advice given in this document. There are, of course, many articles on engaging activities that can be carried out with optical radiation.

Title	Bulletin
Laser attack – article on laser pointer misuse	204
Green lasers	229
Laser guidance (guidance on laser use)	231
UV lamps: model risk assessment	208
Ultraviolet lightbox (making one)	208
Running a low-pressure glass-envelope mercury-vapour lamp	213
Flicker and photosensitive epilepsy	210

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