Laser pointers endanger the retina ?!

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Introduction

With the availability of low cost laser diodes in the visible range, laser pointers have become very popular in both the public and private sector. They are commonly designed for the use in lectures and demonstrations by persons from educational institutions and industry. But they have also become a graze among teenagers who have little understanding of the potential of laser injury.
In the laser pointer a small lens focuses the original divergent laser beam and produces a narrow beam of light, which is insignificant spread over several meters. The typically used laser diodes emit light of a wavelength ranging from 630 to 680 nm.
To pinpoint text on overhead charts, the laser pointer has to be intense enough to be seen on illuminated walls several meters away. On the other hand the intensity must not be hazardous to the eye if somebody should unintentionally look directly into the laser beam.
According to DIN EN 60825-1 [1-3] this is the case when the output power of the Laser in the spectral region between 400 and 700 nm is lower than 1 mW (laser class 2). Furthermore this is true for lasers with a divergent beam, so that only a power of 1 mW can be measured through a 7 mm aperture (laser class 3A). In this part of the spectrum there is a natural aversion to bright light (the blink response) which will limit the exposure time to around 0.25 s. At these low powers an eye hazard can only exist if the blink response is overcome and the individual stares directly into the laser beam. Lasers with higher output power are classified in laser class 3B or 4. These lasers will cause injury to the eye within the time of the blink response. In the American FDA Norm (Code of Federal Register 21 CFR 1040.10 & 1040.22) there is no distinction between laser classes 3A and 3B. All these lasers are classified in laser class IIIA.
Class 3B lasers used in commerce and industry must be notified to the relevant Employer's Liability Insurance Association and the Labour Protection Authorities. Strict protective measures such as wearing laser safety goggles and being given instruction by a laser safety officer must be strictly adhered to [1].

Our investigations attend to the question, if the obtainable laser pointers are correctly classified and how the reduction of the spot size on the retina differs for several laser pointers. We also investigated the beam quality of such laser pointers to answer the question, which reduction of the spot size on the retina can be reached with the eye lens.

Experimental set-up

1. Laser classification:

In order to check the classification we measured the power of the laser behind a 7 mm aperture situated 10 cm from the laser (Fig. 1). The irradiance according to DIN EN was obtained by taking the power measured and dividing it by the aperture area.

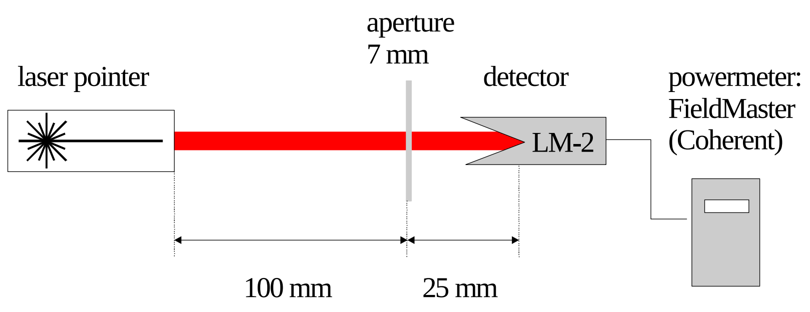

Fig. 1: Experimental set-up for determining irradiance in according to DIN EN 60825-1 (1997).

2. Investigation of the spot size reduction through a stylized eye:

We conducted another study to determine actual irradiance on the retina. We started by determining the laser pointer's real irradiance. Using a CCD camera we mapped the actual spot size of the laser beam at a given distance from the laser. From this image we can determine the area over which the total power is spread. Taking the power measured and dividing it by this area gives the actual average irradiance.

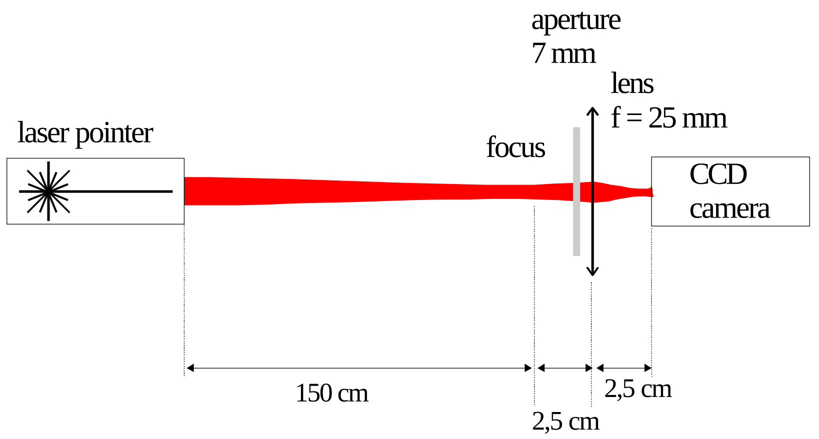

Fig. 2: Experimental set-up to measure the power density on the retina reduced through a stylized eye.

In order to be able to assess the affect of the irradiance falling on the retina the laser beam was scanned using a model eye (Fig. 2). This model eye consists of a 7 mm aperture (pupil) behind which there is a lens with a focal length of 25 mm (corresponding to the total refractive power of the eye) [4,5]. The CCD camera, located 25 mm (eye length) behind the lens, represents the retina.

Thus the beam spot size, mapped by the CCD camera, corresponds to the actual beam spot size on the retina using this model. Dividing the power by the spot size gives the average irradiance.

3. <u>Determination of the beam quality:</u>

The beam quality M^2 is given through the product of far-field beam divergence angle Θ and beam waist radius w_0 [6].

$$M^2 = \frac{\pi}{2 \cdot \lambda} \cdot (\Theta \cdot w_0)$$

M^2 is the number which expresses how many times larger the diameter of a focused beam is, compared with the focus diameter for a pure fundamental Gaussian beam. A Gaussian beam has a beam quality of one. The knowledge of this beam quality number opens the possibility that relatively simple measurements can yield a number which has meaningful utility in propagation calculations for beams of any mix of modes.
In the far-field the beam diameter was measured with the CCD-camera for several distances to the laser beam waist and so the far-field beam divergence angle can be investigated.

Results

In our investigation we measured more than 40 laser pointers from various manufactures or distributors. The irradiance measurement conducted according to DIN EN 60825-1 clearly shows that most of these laser pointers fall under laser class 3B (s. Fig. 3). That means they have an output power of more than 1 mW measured through a 7 mm aperture.

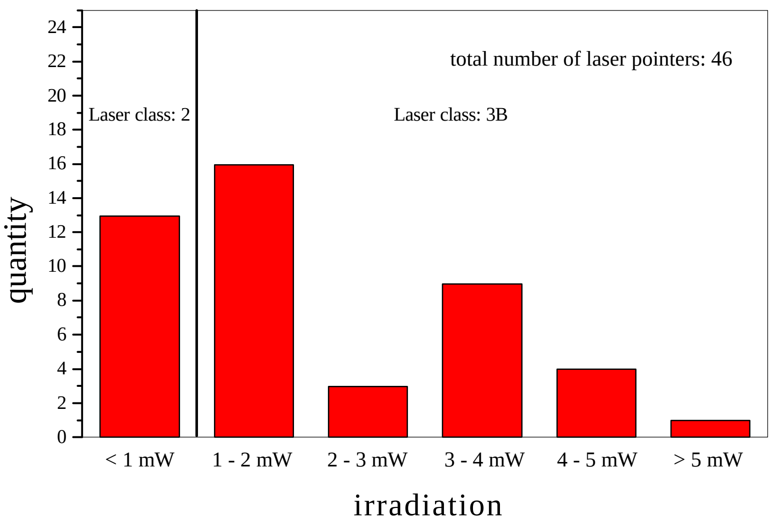

Fig. 3: Power distribution of the investigated laser pointers.

It should also be noted that many of them were not correctly classified by the manufacture or distributor according to DIN EN 60825-1. The highest laser output we found was 6.5 mW !

Fig. 4 gives the image of the intensity of one laser pointer as mapped with the CCD camera. As we can see from the spatial distribution of the irradiance, it is not evenly spread over the area irradiated; on the contrary, it is very inhomogeneous.

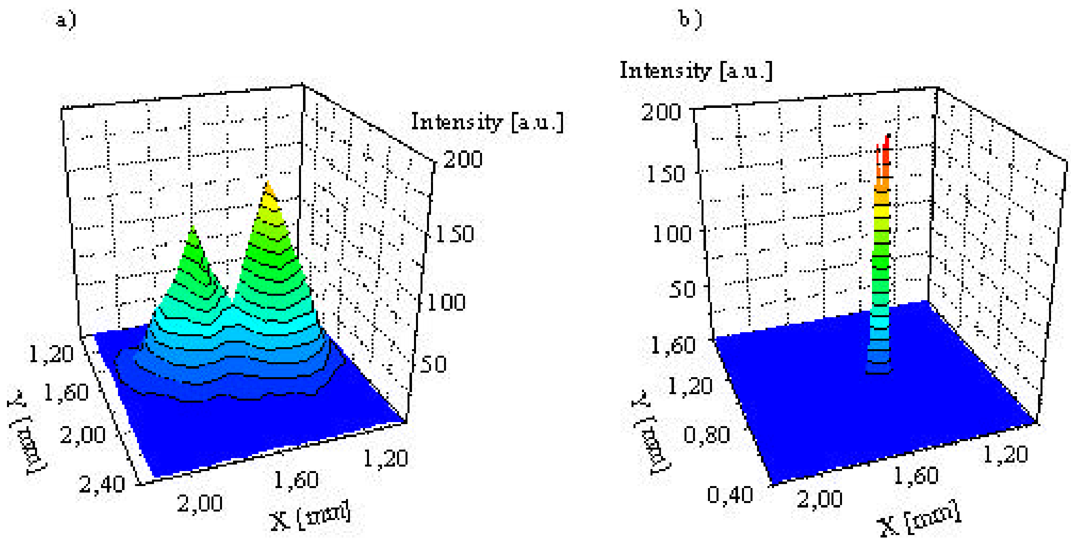

Fig. 4: a) Spatial irradiance of a laser pointer, mapped 1.5 m from laser.
b) Spatial irradiance of the same laser pointer after focusing by model eye.

The figure below shows the spatial distribution of the irradiance after the beam has passed through the model eye. The image 4 b) shows clearly that the beam spot size is much smaller as compared to Fig. 4 a) (the absolute scale in mm is the same for both images).

In laser accidents the so-called "worst-case situation" is that the laser beam is perfectly fixed on the retina during irradiation and the eye produces the minimal focus on the retina without any refraction error or accommodation. Due to the fact that the beam quality of a laser pointer is similar to that of a HeNe laser the minimal reachable spot size on the retina is less than 10 µm.

Potential hazard of a laser pointer

The potential hazard of laser pointers must be analysed under two aspects. In our view dazzling people in a situation where they have to be concentrated (e.g. drivers) is by far the highest danger increased due to the small and unrecognisable size of the laser pointer in someone’s hand. Thus an irradiation is always a very unexpected event with unpredictable reaction of the victim. The second hazard is the reversible or irreversible damage of the retina by direct irradiation. So far no visible irreversible damage is reported to our knowledge after inspection of the retina. However also invisible irreversible damage is reported with laser power less than half of the visible damage threshold. [7] Thus no reported irreversible damage does not mean that there is non.

An ophthalmoscopically visible damage threshold was detected with 9 -15 mW (worst-case) for 150 - 270 ms exposure in the visible range [7,8]. Other much more sensitive methods for damage detection, such as fluorescence angiography, microscopy and electron microscopy, lead to a maximum permissible exposure (MPE) value to be defined as 1/10 of the determined visible threshold. The safety factor of 10 is therefore absolutely necessary.

With a theoretical model [9,10] the temperature increase produced in the retina after exposure can be calculated. The thermal response is dependent upon the wavelength of the incident light, because the absorption coefficients of the choroid, the pigment ephithelium, and anterior ocular media are each depended on wavelength. The model describes both the absorption of intense light and the subsequent transient thermal behaviour of the retina. In the equilibrium model, light is attenuated exponentially by thermally homogeneous ocular tissue whose absorption coefficients are different for different tissue layers.

This model shows that the correct units for measuring the damage threshold of the retina in the visible range is rather W/m than W/cm^2 [11], because the damage with cw laser pointers is thermal and so heat-conduction has to be consider. A diffraction limited image of a point source on the retina would have a diameter of less than 10 µm. In this case the radiation is absorbed within a small area. So the heat flows not only forward and backward to the direction of propagation, but a substantial amount of heat also flow in radial direction. In the case of a greater spot size the heat flow in radial direction would be negligible. That means that the retinal lesion threshold is inversely proportional to the spot size diameter on the retina.

		corneal power to produce 1 °C temperature increase [mW / °C]		
wavelength [nm]	t [s]	σ = 10 µm	σ = 100 µm	σ = 500 µm
514.5	0.01	0.30	6.5	150
	0.1	0.27	2.6	40
	1	0.25	1.9	15
632.8	0.01	0.40	7.9	180
	0.1	0.33	2.9	43
	1	0.32	2.0	15
694.3	0.01	0.47	9.4	210
	0.1	0.40	3.4	50
	1	0.37	2.3	17
840	0.01	1.1	20	450
	0.1	0.87	6.5	93
	1	0.81	4.3	31

Tab. 1: Required total corneal power for 1 °C temperature increase [9].

Table 1 shows the thermal behaviour at 1 µm behind the retina for a Gaussian irradiance distribution. The calculations have been performed with the assumption that the irradiance is constant in time.

For example, a laser pointer with an output energy of 5 mW can produce an temperature increase of 15 °C (700 nm) to 20 °C (500 nm) after 0.1 s exposure (provided a fixed irradiation area). Because of such a temperature increase a thermal microbiological damage is getting probable and serious for longer exposure time.

In an opthalmological report [12] the photocoagulation on a primate retina with an argon laser (514.5 nm, spot size 200 µm, exposure 0.2 s, power 100 mW) was investigated. In this case the calculated temperature increase on the retina is 24 °C. This example shows that with temperatures of round about 20 °C a thermal injury can be produced.

Of course the question rises how likely a spot size of 10 µm can be irradiated for 0.1 to 0.25 seconds with a hand held laser pointer in some distance from the eye. This spot will move rather fast in most (but not all) cases on the retina with much lower heating effect and thus with less or no harm. For the above calculations everybody uses the average value of 0.25 seconds for the aversion or blink response. But is the blink response time the same for the monochromatic light of laser pointers close to the sensitivity edge of the retina near 700 nm? Also little knowledge about the photochemical effect on the photoreceptors of such lasers is known. Clinically the patients which have been irradiated with laser pointers report on flashblindness and later on being very sensible to light at least for several days even with lasers below 1 mW.

Conclusion

The beating argument momentarily is that nothing serious happened so far. The enormous amount of sold laser pointers however will increase the probability of a dazzling or (long time) irradiation event. What can we do to prevent this? We should not trivialise nor dramatise the effect of laser pointers. However the consumer must be sure that the laser pointers are correctly labelled. Generally there has to be more education (also to adults) and suitable penalties for dangerous misuse of these products and they should definitely not be given to kids.

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