LASER SAFETY

version 1.01, 6 Dec 2004, B Chambers G8AGN

DISCLAIMER
The information on which this discussion is based was drawn from the relevant European standard EN 60825-1-1994. The equivalent US standard is ANSI Z136. Although I have taken reasonable care to ensure that the theory and calculations given below are valid, I accept no responsibility whatsoever for any mishap which may arise from the use of this information.

Many of the inexpensive red laser pointers on sale at present, especially the cheap imports, emit much higher powers than their labelling implies. It is imperative, therefore, to get an estimate of the safe viewing distance so as to avoid accidental eye damage. This is especially important if you are looking for a laser beam through binoculars or a sighting scope.

In the discussion which follows, only low powered lasers (< 10 mw) emitting red light will be considered. It is not recommended that you experiment with the higher power IR lasers which are readily available since the risk of inadvertent over-exposure and possible eye damage is much greater than would be the case when using visible sources.

The starting point for our discussion is the Maximum Permitted Exposure. This is the maximum power flux (watts per square metre) which is considered safe for our eyes. For exposures of a few seconds with red light, this can be calculated from the equation

$$E = 18t^{-0.25} \text{ watts/m}^2 \qquad (1)$$

As an example, for an exposure time t = 1 second, E = 18 watts/m^2. This may sound a lot, but on a very sunny day the Sun can produce a power flux of up to 1000 watts/m^2 at the Earth's surface – this is why it's inadvisable to stare at the Sun, as early astronomers found to their cost (especially as the effect is magnified by viewing through a telescope, as will be seen later).

The actual exposure due to viewing a given laser at a distance is given by

$$E = \frac{4PG^2}{\pi(a + r\phi)^2} \text{ watts/m}^2 \qquad (2)$$

where

P = laser output power in watts
G = optical gain of the viewing system (more on this later)
a = diameter of beam emerging from the laser in metres
ϕ = beam divergence in radians
r = distance between the laser and the eye in metres
π = 3.14159

Hence by combining (1) and (2), we can obtain an estimate of the minimum safe viewing distance, r_{min}.

$$r_{\min} = \frac{\sqrt{\dfrac{4PG^2t^{0.25}}{18\pi}} - a}{\phi} \text{ metres} \qquad (3)$$

This formula neglects any attenuation due to the atmosphere since this will have only a very small effect with the laser powers under consideration here since the minimum safe viewing distance will be small (typically less than 1 km).

Let us now return to the discussion of G. If no viewing aid such as a scope or binoculars are being used, then G may be set equal to 1.

The most dangerous viewing conditions for the eye will occur at night when the pupil diameter is at its maximum, typically 7 mm, and a laser is being viewed through a telescope or binoculars since they will collect more light than the naked eye. Let's assume a pair of 10 x 50 binoculars are being used and the laser beam diameter is larger than the objective lens diameter. Then the binocular exit pupil diameter will be 50/10 = 5 mm, which is less than the eye's pupil diameter. Hence we can assume that all the light collected by the binoculars will enter the eye and G can be set to 50/7 = 7.1. If the binocular exit pupil diameter is larger than 7 mm then not all the collected light will enter the eye and G will be smaller, but it's probably better to stick to the worst case (i.e. higher value) for G. In practice there will be less than 100% transmission of light through the collecting optics which will give an extra margin of safety. Nevertheless, I've assumed 100% transmission so as to produce a conservative estimate of the minimum safe viewing distance.

Let's now get a feel for numbers. Consider a red laser with

Output beam diameter = 2 mm
Beam divergence = 1.5 mrad
Viewing time = 1 sec

The table shows the estimated minimum safe viewing distance, in metres, for three laser output powers (1, 5, 10 mW) and two values of viewing optical gain (1, 7)

Laser output power (mW)	G = 1 (naked eye)	G = 7 (binoculars)
1	5	38
5	12	87
10	17	123

In the table, the calculated values have been rounded up to the next whole metre. In practice, the eye will be protected to some extent by the normal reflex action of turning the head away from a bright light, but it is inadvisable to rely on this, especially at the higher power levels.

If the laser is fitted with a beam expander with a magnification ratio of N, then in the calculation the beam diameter, a, should be multiplied by N, i.e. $a' = Na$ and the beam divergence, ϕ, should be divided by N, i.e. $\phi' = \phi/N$.

Hence, with the same lasers as before but now fitted with a X10 beam expander we get

Laser output power (mW)	G = 1 (naked eye)	G = 7 (binoculars)
1	Safe	260
5	Safe	745
10	44	1109

With the lower power lasers, naked eye viewing is now safe because the beam diameter has been increased and hence the flux density impinging on the eye is below the Maximum Permitted Exposure level. When viewing through binoculars, however, the lasers are now more hazardous because the beam expander has decreased the beam divergence and hence increased the power flux collected by the eye.