Appendix A
Laser Basics Abridged

A.1 Laser Light Characteristics

The term "LASER" is an acronym that stands for Light Amplification by Stimulated Emission of Radiation. In 1917 Einstein postulated that a photon released from an excited atom could, upon interacting with a second, similarly excited atom, trigger the second atom into de-exciting itself with the release of another photon. The photon released by the second atom would be identical in frequency, energy, direction, and phase with the triggering photon, and the triggering photon would continue on unchanged. These two photons could then proceed to trigger more photon releases, through the process of stimulated emission. The unique characteristics of laser light/radiation are:

Monochromatic. The light emitted from the classical laser is monochromatic; that is, it is of one color/wavelength. In contrast, ordinary white light is a combination of many colors (or wavelengths) of light.

Coherent. The light from a laser is said to be coherent, which means that the wavelengths of the laser light are in phase in space and time. Ordinary light can be a mixture of many phases. The difference can be compared to a mob walking down the street versus the cadence of a troop of soldiers.

Directional/Divergence. Lasers emit light that is highly directional and has low divergence; that is, laser light is emitted as a relatively narrow beam in a specific direction. Ordinary light, such as from a light bulb, is emitted in many directions away from the source. The beam divergence is the increase in beam diameter with increase in distance (that is, how fast the beam spreads out over distance). Although lasers are unable to produce perfectly collimated beams due to the wave nature of light, the divergence can be made much smaller than with any other available source of optical radiation.

A.2 Common Laser Components

Active medium. To be suitable for a laser, a medium must have at least one excited energy state, which is metastable, where electrons can be "trapped" and cannot immediately and spontaneously transition to lower-energy states. Electrons may remain in these metastable states for anywhere from a few microseconds to several milliseconds. When the medium is exposed to the appropriate pumping energy, the excited electrons are trapped in these metastable states long enough for a *population inversion* to occur (that is, a condition where there are more electrons in this excited state than in the lower state to which these electrons decay when stimulated emission occurs). Active media contain atoms whose electrons may be excited to a metastable energy level by an energy source. Common laser mediums are solid crystals such as ruby or Nd:YAG, liquid dyes, gases such as argon, CO_2, or HeNe, or semiconductors such as GaAs.

Excitation mechanism. These systems pump energy into the laser material, increasing the number of atoms or molecules in the metastable energy state. When the number of atoms or molecules in the metastable energy state exceeds those in the lower level, a population inversion exists, and laser action becomes possible. Several different pumping systems are used, e.g., electrical, chemical, and optical (including other lasers).

Resonator (optical cavity). A preferential direction is established by placing a mirror at each end of the laser material so that the photons of light may be reflected from one mirror to the other, passing back and forth through the laser medium. Lasers are constructed in this way so that the photons pass through the medium many times and are continuously amplified each time. One of the mirrors is only partially reflecting and permits a fraction of the beam energy to be transmitted out of the cavity; this fraction is the laser beam we use.

A.3 Modes of Operation

The different modes of operation of a laser are distinguished by the rate at which energy is delivered.

Continuous wave (CW). Lasers operate with a stable average beam power. In most higher-power systems, one is able to adjust the power. In low-power gas lasers such as HeNe, the power level is fixed by design and performance, and it usually degrades with long-term use.

Single pulsed. Lasers generally have pulse durations of a few hundred microseconds to a few milliseconds. This mode of operation is sometimes referred to as long pulse or normal mode.

Single-pulsed Q-switch. Lasers are the result of an intracavity delay (Q-switch cell), which allows the laser media to store a maximum of potential energy. Then, under optimum gain conditions, emission occurs in single pulses; typically of 10^{-8}-sec time domain. These pulses will have high peak powers often in the range of 10^6–10^9 W.

Repetitively pulsed. Lasers generally involve the operation of pulsed laser performance operating at fixed (or variable) pulse rates, which may range from a few pulses per second to as high as 10,000,000 pulses per second.

Mode locked. Lasers operate as a result of the resonant modes of the optical cavity. These modes can affect the characteristics of the output beam. When the phases of different frequency modes are synchronized, i.e., "locked together," the different modes will interfere with one another to generate a beat effect. The result is a laser output that is observed as regularly spaced pulsations. Lasers operating in this mode-locked fashion usually produce a train of regularly spaced pulses. A mode-locked laser can deliver much higher peak powers than the same laser operating in the Q-switched mode. The output from mode-locked laser pulses will have enormous peak powers, often around 10^{12}-W peaks.

Appendix B
Laser Calculation Hints

Contributed by Robert J. Thomas

B.1 Useful Approximations

Software exists to perform the most common laser safety calculations: OD, NHZ, OD at different distances, and NOHZ. Still, having knowledge of where these values originate is important. With that in mind, one must turn to Z136.1 for MPE values, correction factors, etc. The tables in ANSI Z136.1 may look bewildering, but they are worth learning how to use. The values listed in the tables are the maximum safe energy that may be incident upon the eye. As the tables illustrate, this energy is a rather complicated function of wavelength and the duration of exposure. In some places, a single value suffices for a broad range of conditions. In other cases, notably those of visible and near-IR radiation during ordinary time periods of exposure, the MPE should be calculated on a case-by-case basis. For these purposes, it is worth using the following assumptions:

(1) Exposure duration time of inadvertent exposure to visible radiation = 0.25 sec (aversion response).
(2) Exposure duration time of inadvertent exposure to UV radiation = 100 sec and NIR radiation = 10 sec (natural eye motion).
(3) Exposure duration time of exposure for intentional viewing = 10^2 sec (e.g., during laser alignment, 600 sec).
(4) Exposure duration time of long-term exposure = 3×10^4 sec (24 hours).

Once you have determined MPE relevant to a particular application, you must calculate the level of incident radiation at your eye under a variety of circumstances (direct exposure or reflected exposure, also called diffuse exposure). Important parameters for such calculations are the optical path length from the laser output to the eye, the beam diameter and divergence, the limiting aperture of the eye, whether the beam is viewed as a point or extended source, and whether a reflection is considered specular or diffuse.

B.2 Important Conventions

Before calculating actual numbers, you must be sure you have the right starting values and units. The three important numbers found in laser manuals are the beam diameter a, the beam divergence f, and the radiant energy Q or radiant power F. These values appear in safety calculations, where they have the units of cm, radians, J, and W, respectively. The central quantities in a laser safety calculation, however, are the radiant exposure H (measured in $\mathrm{J \cdot cm^{-2}}$) and the irradiance E (measured in $\mathrm{W \cdot cm^{-2}}$). These values are less common in the front of laser manuals. There may also be some confusion regarding the profile of your beam and the choice of beam diameter.

The most common profile of a laser beam is a Gaussian profile. The diameter a of a Gaussian beam is specified according the $1/e$ or $1/e^2$ point. Laser manufacturers may often use the $1/e^2$ definition since this area encompasses almost 90% if the total beam energy. However, safety calculations use the $1/e$ diameter, so check which one you are using. The two diameters have a simple relation:

$$a\left(\frac{1}{e^2}\right) = \sqrt{2}a\left(\frac{1}{e}\right).$$

Your beam may not have a Gaussian profile. Another common profile is the top hat, in which the beam's radiant exposure is equal for all points within the beam diameter. This mode makes the beam diameter and irradiance very easy to define. For a beam with a top

Table B.1 Limiting apertures for nonvisible wavelengths.

Spectral Region	Period of Exposure (sec)	Aperture Diameter (mm)
180–400 nm	10^{-9}–0.25 0.25–3×10^4	1.0 3.5
400–1400 mm	10^{-9}–3×10^4	7.0
1400 nm–100 mm	10^{-9}–0.25 10–3×10^4	1.0 3.5
100–1000 mm	10^{-9}–3×10^4	11.0

hat profile, beam diameter a, and radiant power F,

$$E_0 = \frac{4\Phi}{\pi a^2}.$$

The subscript for E identifies it as the maximum irradiance, i.e., at zero distance from the laser's exit port. The radiant exposure is calculated from this by dividing H by the appropriate exposure time or pulse duration.

For a Gaussian beam, the central irradiance will be different from the average irradiance over the area within the beam diameter. However, the MPE is not determined according to the peak irradiance of the beam; it is determined by averaging the incident power of the beam over an area defined by the *limiting aperture* of the eye. For visible light this limiting aperture is the diameter of a fully dilated pupil, which is 7 mm. For nonvisible radiation, other limiting apertures are defined in Table B.1.

B.2.1 Repetitively pulsed lasers (RPLs)

Because of high RPL peak intensity, the MPE from a pulsed laser is more complicated than for an equivalent continuous source. To determine the correct MPE for f = a given train of pulses, you must know the pulse repetition frequency F, the duration of a single pulse t, the total duration of a train of pulses T, and the total exposure time $T_{\max}$.

There are three rules that limit the MPE per pulse for a train of laser pulses:

Table B.2 Minimal angle specifications.

Exposure Time (sec)	Angle α_{min} (mrad)
≤0.7	1.5
0.7–10	$2t^{\frac{3}{4}}$
≥10	11

1. The MPE/pulse is limited to the MPE for any single pulse (single-pulse limit).
2. The MPE/pulse is limited to the MPE for all exposure times between T and T_{max}, divided by the number of pulses n during that time period (average power limit).
3. The MPE/pulse is limited to the MPE for a single pulse multiplied by $n^{-\frac{1}{4}}$, where n is the number of pulses that occur during the period of exposure T_{max} (repetitive pulse limit). This rule is applied only to thermal damage MPE values and is further described in terms of a t_{min} factor (see Thomas et al., 2001).

Above a critical frequency (>55 kHz for visible lasers), Rule 2 gives the lowest value. In other cases, all three limits should be checked.

B.2.2 Extended-source viewing

If a laser beam has a high divergence or is viewed at a close distance relative to the beam diameter, the image formed by the beam upon the retina may not be a point. In this case, the laser is an extended source, and the MPE should be corrected accordingly. Extended-source MPEs are applied only in the spectral region 400–1400 nm and where the angle subtended by the eye to capture the entire beam is greater than a minimum angle specified for differing exposure times (Table B.2).

If the laser beam subtends an angle greater than the minimum for particular viewing circumstances, then the MPE should be multiplied by the factor a/a_{min}. Extended-source viewing may apply in cases such as viewing a beam after passing through an optic, or viewing a diffuse reflection at close distance. However, since an extended-source correction factor increases the MPE, it is generally sufficient to perform your calculations simply assuming a point source (worst case scenario).

B.2.3 Diffuse reflections

The major feature of Class 4 lasers such as those found in research laboratories is the fact that even diffuse reflections can be hazardous; therefore, it is important to understand how to calculate the power of a diffusely reflected laser beam.

The flux of energy through a point at a given distance and angle from a diffusely reflecting surface is:

$$H = \frac{\rho_\lambda Q \cos \theta_v}{\pi r^2},$$

where r is the reflectance at the wavelength in question, Q is the energy of the incident beam, θ_v is the angle of observation with respect to the normal, and r is the distance from the point of reflection to the point of observation. For safety calculations, this equation can be greatly simplified by assuming that $r_l = \cos q_n = 1$.

B.2.4 Nominal hazard zones

Having determined the MPE for a specific laser operating in a specific mode, you can now define a nominal hazard zone (NHZ), the area around your laser within which the beam exceeds the MPE. To do this you need to know how your beam diameter changes with distance. A Gaussian beam actually changes its diameter according to a hyperbolic function, with the minimum diameter occurring at the *beam waist*. However, for safety calculations you can use one of two approximations. For lasers in which the beam waist is at or in front of the exit port, the diameter D of a Gaussian beam at a given distance r is given by the following formula:

$$D = \sqrt{a^2 + (r - r_0)^2 \phi^2},$$

where a is the beam diameter at the exit port. Depending on the situation, you may further simplify this equation by dropping the r_0 (waist close to exit port), a (large distance r), or the whole thing (for a large diameter, low divergence, and short distance, $D \approx a$). In cases where the beam waist is behind the exit port, it may be more appropriate to use a linear approximation:

$$D = a + r\phi.$$

B.2.5 Protective eyewear

If the MPE for a particular situation can be calculated, determining the correct eyewear is easy. Simply calculate the radiant exposure or irradiance of the beam under the circumstances of your experiment, calculate the corresponding MPE, and take the logarithm of the quotient:

$$OD = \log_{10} \frac{H}{MPE : H} = \log_{10} \frac{E}{MPE : E}.$$

The OD obtained is the minimum required to protect your eyes. Round up to the nearest whole number that is commercially available. In some cases it may be appropriate to have two sets of goggles available, one with a low OD that provides maximum visibility during alignment and low-power operation, and another with a high OD for full-power applications.

Note that three references are provided from the *Journal of Laser Applications* which describe hazard analysis methodologies in more detail and in a procedural fashion (Thomas et al.).

References (further reading)

Thomas, R. J., Rockwell, B. A., Marshall, W. J., Aldrich, R. C., Zimmerman, S. A. and Rockwell, R. J., "A procedure for multiple-pulse maximum permissible exposure determination under the Z136.1-2000 American National Standard for Safe Use of Lasers," *Journal of Laser Applications* **13(4)**, 2001.

Thomas, R. J., Rockwell, B. A., Marshall, W. J., Aldrich, R. C., Gorshboth, M. F., Zimmerman, S. A. and Rockwell, R. J., "A procedure for the estimation of intrabeam hazard distances and optical density requirements under the ANSI Z136.1-2000 Standard," *Journal of Laser Applications* **16(3)**, 2004.

Thomas, R. J., Rockwell, B. A., Marshall, W. J., Aldrich, R. C., Gorshboth, M. F., Zimmerman, S. A. and Rockwell, R. J., "A procedure for the estimation of intrabeam hazard distances and optical density requirements under the Z136.1-2000 American National Standard for Safe Use of Lasers," *Journal of Laser Applications* **19(1)**, 2007.

Appendix C
Laser Safety Illustrations

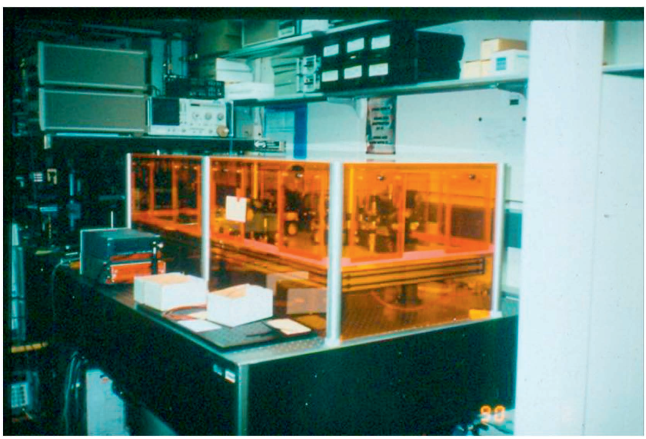

Figure C.1 Example of an enclosure made from acrylics with built-in OD. This contains all stray reflections inside the enclosure. It can be custom or homemade.

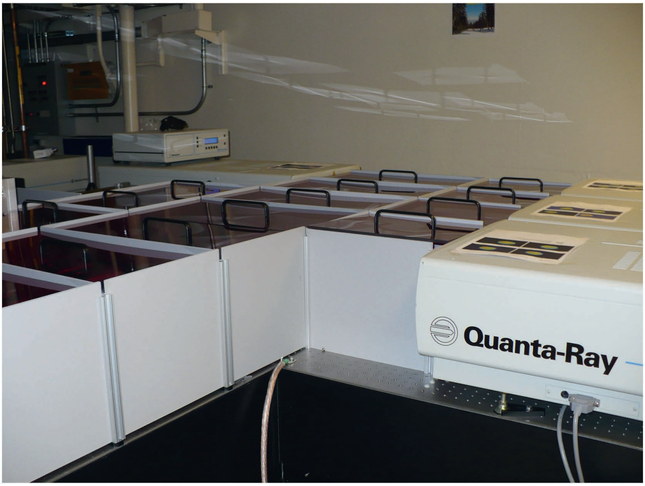

Figure C.2 Compartmentalization. A large, open, beam path enclosed using a compartmentalization approach. Holes through interior panels let the beam move across the table.

Figure C.3 A locked enclosure. This is a small table-top enclosure. The side panels are locked, and the curtain in the background goes around the table to create a room-within-a-room effect. Other enclosures are shown in Figs. C.4 and C.5.

Figure C.4 Enclosure example.

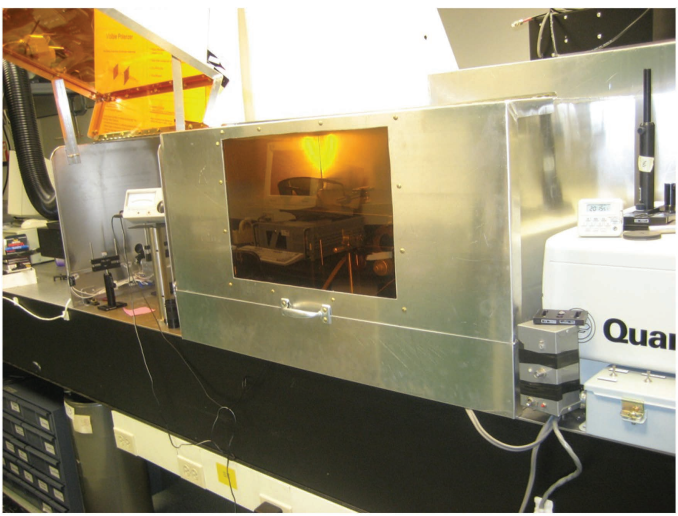

Figure C.5 Enclosure example.

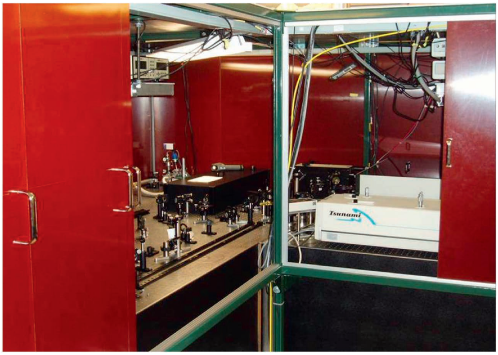

Figure C.6 An 80/20 frame. The frame stands off from a table. Its panels slide open for access. The top is closed. It is equipped with lights for visibility, and it can have a HEPA filter for cleanliness.

Figure C.7 Rather than interlock a laser, here we have a combination lock used to keep unauthorized people out. It is not tied to the laser. Each user can have a separate access code. The door is always locked from the outside.

Figure C.8 Laser eyewear is best stored in one central location (not a box). Eyewear does not need to be stored outside the lab; storage directly inside the entrance is acceptable.

Figure C.9 Eyewear storage possibility.

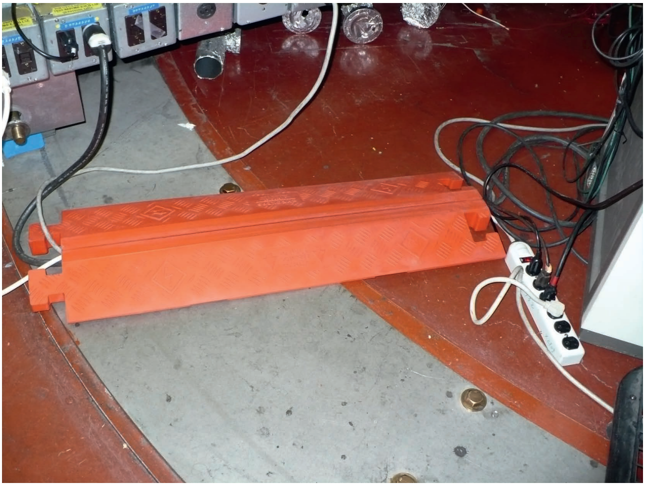

Figure C.10 Trip hazards, wires, and hoses can be reduced with the use of heavy-duty plastic bridges that contain precut grooves and can be linked together.

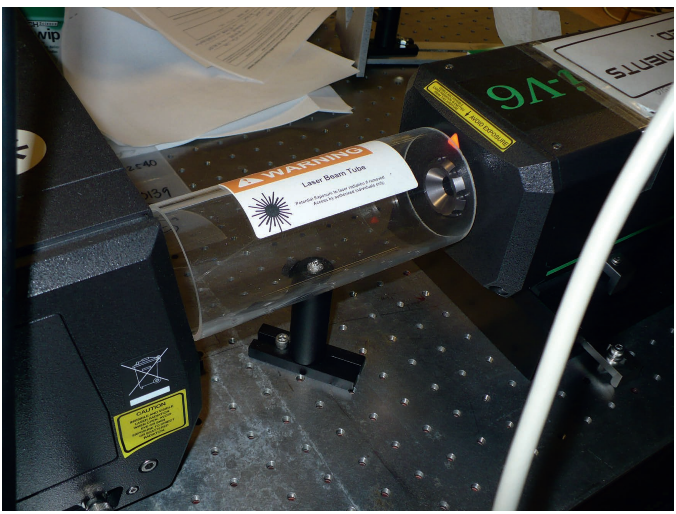

Figure C.11 The pump-beam path is usually very short and has no reason for being an open pathway. The beam tube can be opaque or visible.

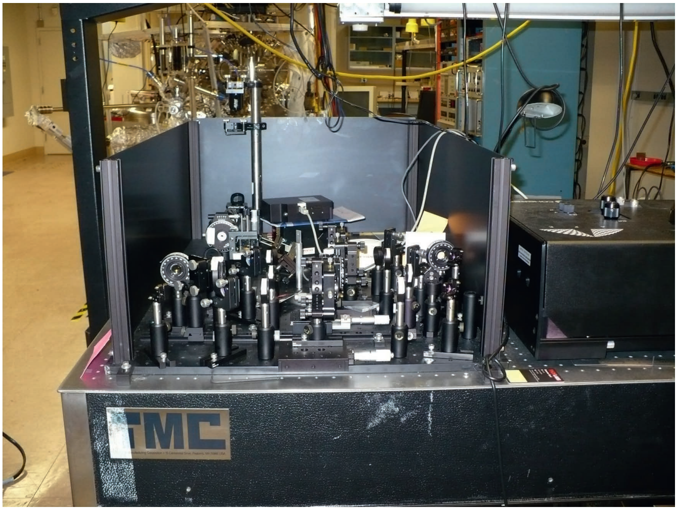

Figure C.12 The role of a perimeter or curb guard is to contain stray beams to the table top. This approach can be easier than placing beam blocks behind every optic. A diffuse inner surface is the best approach.

Figure C.13 Window leading into a vacuum chamber/end station. The controls include a plastic cover to block any stray reflections from leaving the chamber, a warning label for hazard communication, and bolt lock to make any violation of this window willful.

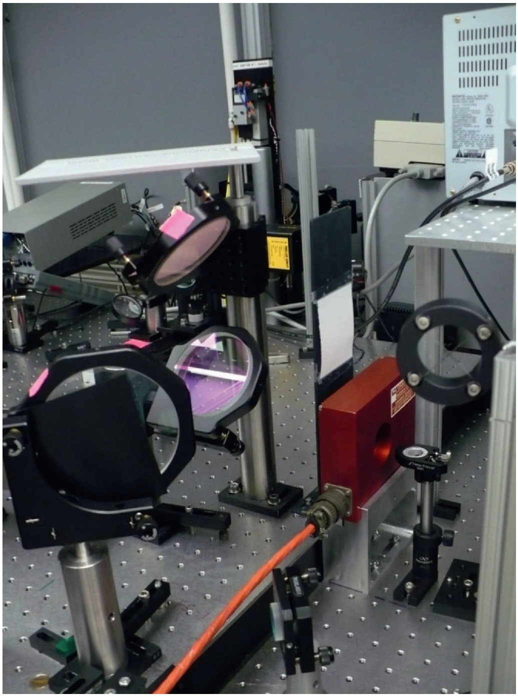

Figure C.14 A vertical block. A vertical beam can be an easily overlooked eye hazard. Awareness signs are useful, but a beam block of one sort or another is even better.

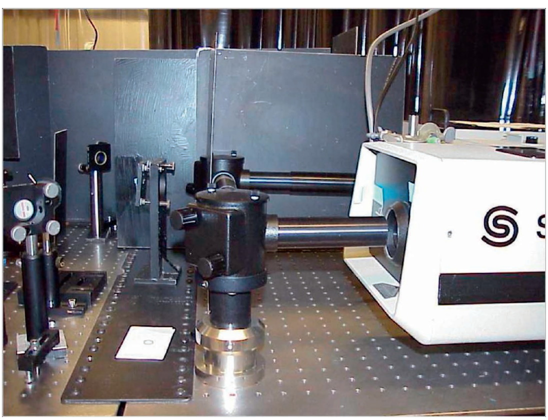

Figure C.15 Optic is entirely enclosed by opaque beam tubes.

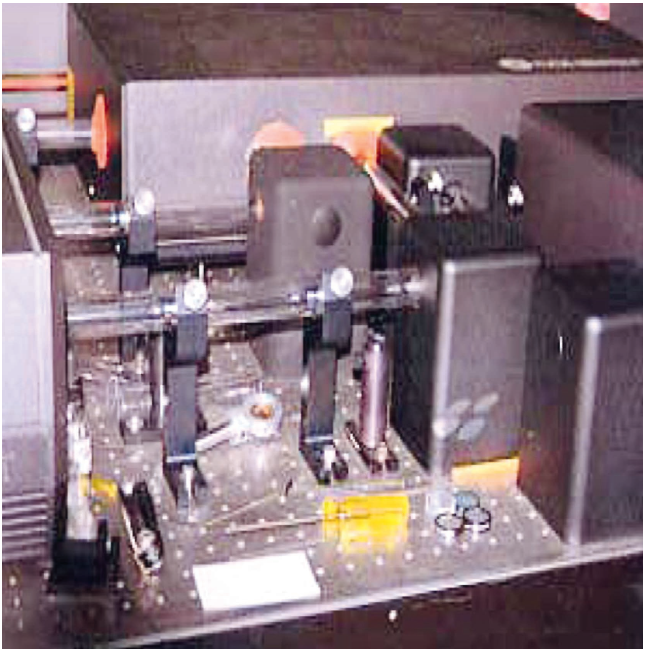

Figure C.16 Optic is entirely enclosed by clear beam tubes.

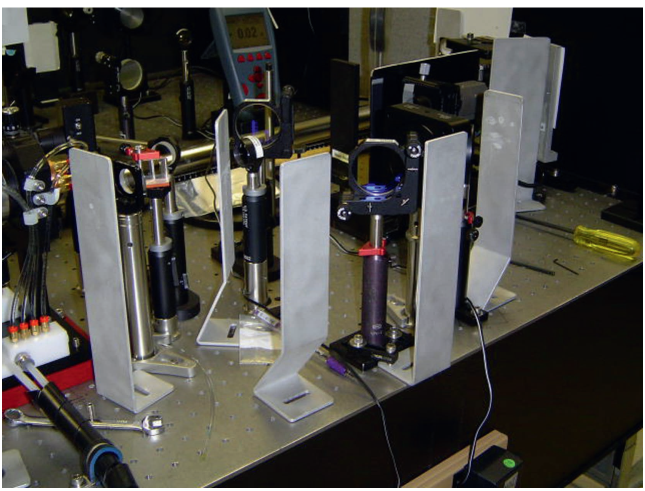

Figure C.17 Beam blocks or perimeter guards should be used as often as needed.

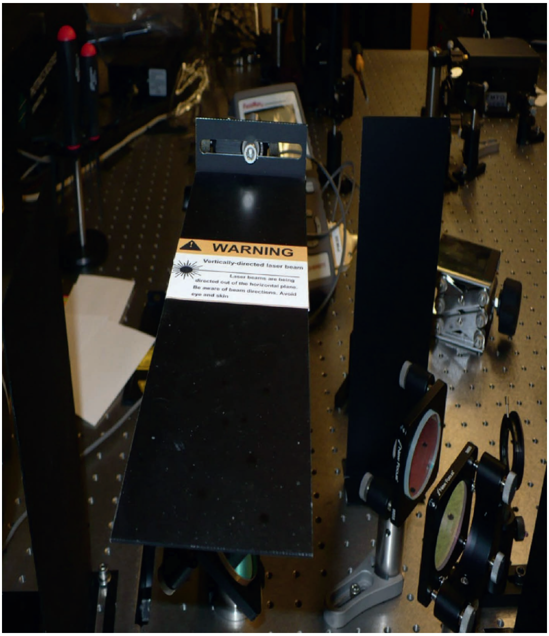

Figure C.18 A vertical beam can be an easily overlooked eye hazard. Awareness signs are useful, but a beam block of one sort or another is even better; here we have both.

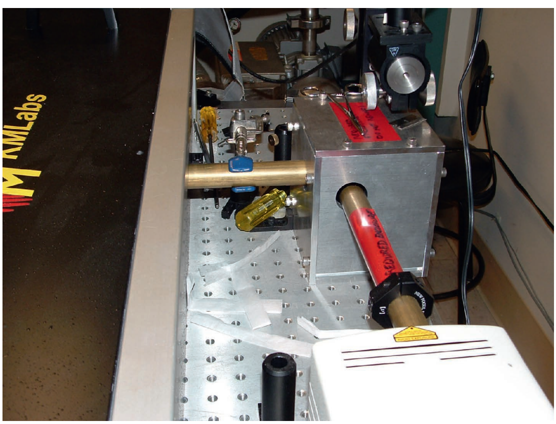

Figure C.19 Beam path between enclosures. The pump-beam path is usually very short and has no reason for being an open pathway. The beam tube can be opaque or visible.

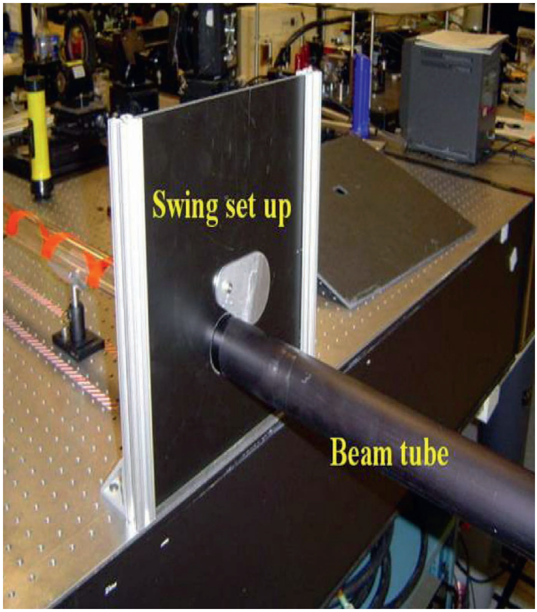

Figure C.20 Beam across a walkway. This is a clever solution: the beam tube falls out, and a swing arm or guillotine falls into place (beam is blocked). The beam is directed off the table with the tube in place, and the swing block contains the beam on the table.

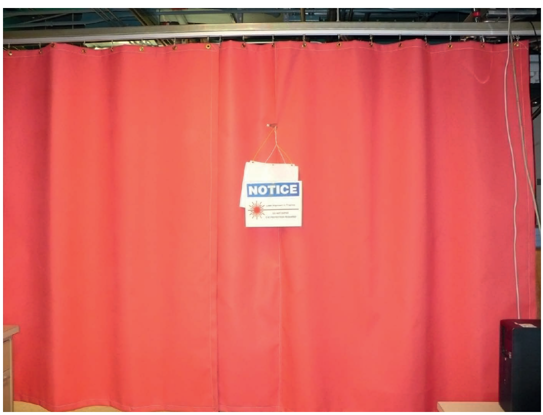

Figure C.21 Curtains can be used to segregate a room into laser areas and laser-free areas, to block stray beams from exiting the room over doors or windows, and to reduce stray light onto the experiment.

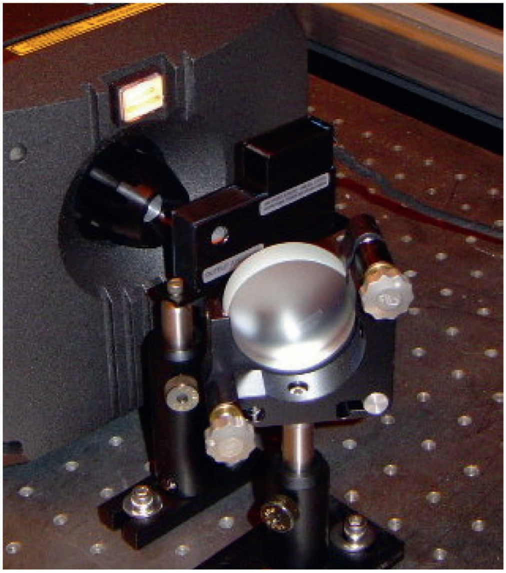

Figure C.22 External shutter.

Figure C.23 Thermal luminescence sheets are used to detect mid- and far-IR wavelengths.

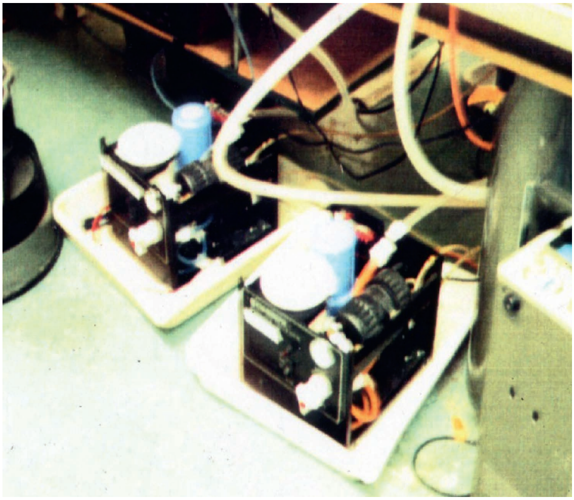

Figure C.24 Dye pumps require secondary containment. A metal tray (Fig. C.25) is best, but plastic is acceptable. The tray needs enough volume to collect spilled dye.

Figure C.25 Metal tray.

Figure C.26 Flashing LED lights can be used during special circumstances, such as administrative controls, when interlock is not functioning, and during service work and alignment.

Appendix D
Glossary

α_{max}. The angular subtense of an extended source beyond which additional subtense does not contribute to the hazard and need not be considered.

α_{min}. The angular subtense of a source below which the source can be effectively considered as a point source. The value of α_{min} is 1.5 mrad.

absorption. Transformation of radiant energy to a different form of energy by interaction with matter.

accessible emission limit (AEL). The maximum accessible emission level permitted within a particular laser-hazard class.

administrative controls. Control measures incorporating administrative means [e.g., training, safety approvals, LSO designation, and standard operating procedures (SOP)] to mitigate the potential hazards associated with laser use.

aperture. An opening, window, or lens through which optical radiation can pass.

attenuation. The decrease in the radiant flux as it passes through an absorbing or scattering medium.

authorized personnel. Individuals approved by management to operate, maintain, service, or install laser equipment.

average power. The total energy in an exposure or emission divided by the duration of the exposure or emission.

aversion response. Closure of the eyelid, eye movement, pupillary constriction, or movement of the head to avoid an exposure to a noxious or bright-light stimulant. In this standard, the aversion response to an exposure from a bright, visible laser source is assumed to limit the exposure of a specific retinal area to 0.25 sec or less.

beam. A collection of light/photonic rays characterized by direction, diameter(s), and divergence or convergence angle(s).

beam diameter. The distance between diametrically opposed points in that cross-section of a beam where the power per unit area is $1/e$ (0.368) times that of the peak power per unit area.

certified laser. A laser product that has been built to the laser product performance standard (CFR 29, part 1040.1) and for which such documentation has been submitted to the CDRH.

coherent. A beam of monochromatic radiation that, by its very nature, has a fixed phase relationship across (spatial coherence) and along (temporal coherence) the path of that beam.

collecting optics. Lenses or optical instruments having magnification and thereby producing an increase in energy or power density. Such devices may include telescopes, binoculars, microscopes, or loupes. Note: Normal or prescription eyewear is not considered to be collecting optics.

collimated beam. Effectively, a "parallel" beam of light with very low divergence or convergence.

continuous wave (CW). A laser operating with a continuous output for a period of $\geq$0.25 sec.

controlled area (laser). An area where the occupancy and activity of those within it are subject to control and supervision for the purpose of protection from laser radiation hazards.

cornea. The transparent outer layer of the human eye that covers the iris and the crystalline lens. The cornea is the main refracting element of the eye.

critical frequency. The pulse repetition frequency above which the laser output is considered continuous wave (CW).

dazzler. Handheld laser, green color output, designed to optically inhibit human target.

diffuse reflection. Change of the spatial distribution of a beam of radiation when it is reflected in many directions by a surface or by a medium.

divergence. The increase in the diameter of the laser beam with distance from the exit aperture, based on the full angle at the point where the irradiance (or radiant exposure for pulsed lasers) is $1/e$ times the maximum value.

effective energy. Energy, in joules, through the applicable measurement aperture. Symbol: Q_{eff}.

effective power. Power, in watts, through the applicable measurement aperture. Symbol: Φ_{eff}.

electromagnetic radiation. The flow of energy consisting of orthogonally vibrating electric and magnetic fields lying transverse to the direction of propagation. Gamma rays, x rays, and UV, visible, IR, and radio waves occupy various portions of the electromagnetic spectrum and differ only in frequency, wavelength, and photon energy.

embedded laser. An enclosed laser that has a higher classification than the laser system in which it is incorporated, where the system's lower classification is appropriate due to the engineering features limiting accessible emission.

enclosed laser. A laser that is contained within a protective housing of itself or of the laser or laser system in which it is incorporated. Opening or removing of the protective housing provides additional access to laser radiation above the applicable MPE than is possible with the protective housing in place (an embedded laser is an example of one type of enclosed laser).

energy. The capacity for doing work. Energy content is commonly used to characterize the output of pulsed lasers and is generally expressed in joules (J). Symbol: Q.

engineering controls. Methods of protecting people from exposure to laser radiation that require no training on the behalf of those who may be exposed. Examples include interlocks and barriers.

erythema. For the purposes of the standard, redness of the skin due to exposure from laser radiation.

extended source. A source of optical radiation with an angular subtense at the cornea larger than α_{min}.

fail-safe interlock. An interlock where the failure of a single mechanical or electrical component of the interlock will cause the system to go into, or remain in, a safe mode.

field of view. The full solid angle from which a detector's active area receives radiation.

focal length. The distance from the secondary nodal point of a lens to the secondary focal point. For a thin lens imaging a distant source, the focal length is the distance between the lens and the focal point.

focal point. The point toward which radiation converges or from which radiation diverges or appears to diverge.

hertz (Hz). The unit that expresses the frequency of a periodic oscillation in cycles per second.

infrared (IR) radiation. Electromagnetic radiation with wavelengths that lie within the range 700 nm to 1 mm.

intrabeam viewing. The viewing condition whereby the eye is exposed to all or part of a laser beam.

iris. The circular pigmented structure that lies between the aqueous and lens of the human eye. The iris is perforated by the pupil.

irradiance. Radiant power incident per unit area upon a surface, expressed in watts per centimeter squared ($W \cdot cm^{-2}$). Symbol: E.

joule (J). A unit of energy. 1 joule = 1 Newton · meter; 1 joule = 1 watt · second.

Lambertian surface. An ideal (diffuse) surface whose emitted or reflected radiance is independent of the viewing angle.

laser. A device that produces radiant energy predominantly by stimulated emission. Laser radiation may have a high degree of spatial and temporal coherence. An acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

laser barrier. A device used to block or attenuate to safe levels incident direct or diffuse laser radiation. Laser barriers are frequently used during times of service to the laser system when it is desirable to establish a boundary for a controlled laser area.

laser classification. An indication of the beam hazard level of a laser or laser system during normal operation. The hazard level of a laser or laser system is represented by a number or a numbered capital letter. The laser classifications are Class 1, Class 1M, Class 2, Class 2M, Class 3R, Class 3B, and Class 4. In general, the potential beam-hazard level increases in the same order.

laser diode. A laser employing a forward-biased semiconductor junction as the active medium.

laser pointer. A laser product that is usually handheld that emits a low-divergence visible beam and is intended for designating specific objects or images during discussions, lectures or presentations as well as for the aiming of firearms or other visual targeting practice. These products are normally Class 2 or Class 3R.

laser safety officer (LSO). One who has authority and responsibility to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards.

laser system. An assembly of electrical, mechanical, and optical components that includes a laser.

lesion. An abnormal change in the structure of an organ or body part due to injury or disease.

macula. The small, uniquely pigmented specialized area of the retina of the eye, which, in normal individuals, is predominantly employed for acute central vision (i.e., area of best visual acuity).

magnified viewing. Viewing a small object through an optical system that increases the apparent object size. This type of optical system can make a diverging laser beam more hazardous (e.g., using a magnifying optic to view an optical fiber emitting a laser beam).

maintenance. Performance of those adjustments or procedures (specified in the user information provided by the manufacturer and considered preventative to maintain optimal performance of the laser system) that are to be carried out by the user to ensure the intended performance of the product. Maintenance does not include *operation* or *service* as defined in this section.

maximum permissible exposure (MPE). The level of laser radiation to which an unprotected person may be exposed without adverse biological changes in the eye or skin.

meter. A unit of length in the International System of Units; currently defined as the length of a path traversed in vacuum by light during a period of 1/299792458 sec. Typically, the meter is subdivided into the following units:

$$\text{centimeter (cm)} = 10^{-2}\ \text{m}$$
$$\text{millimeter (mm)} = 10^{-3}\ \text{m}$$
$$\text{micrometer } (\mu\text{m}) = 10^{-6}\ \text{m}$$
$$\text{nanometer (nm)} = 10^{-9}\ \text{m.}$$

minimum viewing distance. The minimum distance at which the eye can produce a focused image of a diffuse source, usually assumed to be 10 cm.

monochromatic light. Having or consisting of one color or wavelength.

nominal hazard zone (NHZ). The space within which the level of the direct, reflected, or scattered radiation may exceed the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE.

nominal ocular hazard distance (NOHD). The distance along the axis of the unobstructed beam from a laser, fiber end, or connector to the human eye beyond which the irradiance or radiant exposure is not expected to exceed the applicable MPE.

nonbeam hazard. A class of hazards that result from factors other than direct human exposure to a laser beam.

OEM. Original equipment manufacturer.

open beam path. A laser beam path where any portion of the beam is accessible without defeating an engineering control.

operation. The performance of the laser or laser system over the full range of its intended functions (normal operation). This does not include *maintenance* or *service* as defined in this section.

optical density (OD). The logarithm to the base ten of the reciprocal of the transmittance at a particular wavelength.

optically aided viewing. Viewing with a telescopic (binocular) or magnifying optic. Under certain circumstances, viewing with an optical aid can increase the hazard from a laser beam. See *magnified viewing* and *telescopic viewing*.

photochemical effect. A biological effect produced by a chemical action brought about by a molecule's absorption of photons that, in turn, directly alters the molecule.

photosensitizers. Substances that increase the sensitivity of a material to exposure by optical radiation.

pigment epithelium (of the retina). The layer of cells that contains brown or black pigment granules next to and behind the rods and cones.

plasma radiation. Blackbody radiation generated by luminescence of matter in a laser-generated plume.

point source. For purposes of this book, a source with an angular subtense at the cornea equal to or less than α_{min}, i.e., ≤1.5 mrad.

point source viewing. The viewing condition whereby the angular subtense of the source, α_{min}, is equal to or less than the limiting angular subtense α_{min}.

power. The rate at which energy is emitted, transferred, or received. Unit: watts (W); 1 watt = 1 joule/second.

procedural controls. Methods or instructions that specify rules, work practices, or both, that implement or supplement engineering controls and that may specify the use of personal protective equipment.

protective housing. An enclosure that surrounds the laser or laser system and prevents access to laser radiation above the applicable MPE. The aperture through which the useful beam is emitted is not part of the protective housing. The protective housing limits access to other associated radiant energy emissions and to electrical hazards associated with components and terminals, and may enclose associated optics and a workstation.

pulse duration. The duration of a laser pulse, usually measured as the time interval between the half-power points on the leading and trailing edges of the pulse. Typical units:

$$\text{microsecond } (\mu\text{s}) = 10^{-6} \text{ sec}$$
$$\text{nanosecond (ns)} = 10^{-9} \text{ sec}$$

$$\text{picosecond (ps)} = 10^{-12}\ \text{sec}$$
$$\text{femtosecond (fs)} = 10^{-15}\ \text{sec}$$
$$\text{attosecond (as)} = 10^{-18}\ \text{sec.}$$

pulse-repetition frequency (PRF). The number of pulses occurring per second, expressed in hertz. Symbol: F.

pulsed laser. A laser that delivers its energy in the form of a single pulse or a train of pulses. In this standard, the duration of a pulse is less than 0.25 sec.

pupil. The variable aperture in the iris through which light travels to the interior of the eye.

Q-switch. A device for producing very short (~10–250 ns), intense laser pulses by enhancing the storage in, and dumping of energy out, of the lasing medium.

radian (rad). A unit of angular measure equal to the angle subtended at the center of a circle by an arc whose length is equal to the radius of the circle. 1 radian ~57.3 deg; 2π radians = 360 deg.

radiance. Radiant flux or power output per unit area per unit solid angle expressed in watts per centimeter squared per steradian ($W \cdot cm^{-2} \cdot sr^{-1}$). Symbol: L.

radiant energy. Energy emitted, transferred, or received in the form of radiation. Unit: joules (J). Symbol: Q.

radiant exposure. Surface density of the radiant energy received, expressed in units of joules per centimeter squared ($J \cdot cm^{-2}$). Symbol: H.

radiant flux. Power emitted, transferred, or received in the form of radiation. Symbol: Φ. Unit: watts (W). Synonym: *radiant power*.

radiant power. Power emitted, transferred, or received in the form of radiation, expressed in watts (W). Synonym: *radiant flux*.

reflectance. The ratio of total reflected radiant power to total incident power. Synonym: *reflectivity*.

reflection. Deviation of radiation following incidence on a surface.

refraction. The bending of a beam of light in transmission through an interface between two dissimilar media or in a medium whose refractive index is a continuous function of position (graded-index medium).

refractive index (of a medium). Denoted by n, the ratio of the velocity of light in a vacuum to the phase velocity in the medium. Synonym: *index of refraction*.

repetitively pulsed laser. A laser with multiple pulses of radiant energy occurring in a sequence.

retina. The sensory tissue that receives the incident image formed by the cornea and lens of the human eye.

retinal hazard region. Optical radiation with wavelengths of 400–1400 nm, where the principal hazard is usually to the retina.

secured enclosure. An enclosure to which casual access is impeded by an appropriate means, e.g., a door secured by a magnetically or electrically operated lock or latch, or by fasteners that need a tool to be removed.

service. The performance of procedures, typically defined as repair, to bring the laser or laser system or laser product back to full and normal operational status. It does not include *operation* or *maintenance* as defined in this section.

solid angle. The three-dimensional angular spread at the vertex of a cone measured by the area intercepted by the cone on a unit sphere whose center is the vertex of the cone. Solid angle is expressed in steradians (sr).

source. A laser or a laser-illuminated reflecting surface.

spectator. An individual who wishes to observe or watch a laser or laser system in operation, and who may lack the appropriate laser safety training.

specular reflection. A mirror-like reflection.

standard operating procedure (SOP). Formal written description of the safety and administrative procedures to be followed in performing a specific task.

steradian (sr). The unit of measure for a solid angle. There are 4π steradians about any point in space.

T_{max}. The total expected or anticipated exposure duration. T_{max} may differ depending on its use.

t_{min}. For a pulsed laser, the maximum duration for which the MPE is the same as the MPE for a 1-ns exposure. For thermal biological effects, this corresponds to the *thermal confinement duration* during which heat flow does not significantly change the absorbed energy content of the thermal relaxation volume of the irradiated tissue.

telescopic viewing. Viewing an object from a long distance with the aid of an optical system that increases the visual size of the image. The system (e.g., binoculars) generally collects light through a large aperture, thus magnifying hazards from large-beam, collimated lasers.

thermal effect. An effect brought about by the temperature elevation of a substance due to laser exposure.

threshold limit (TL). The term is applied to laser-protective eyewear filters, protective windows, and barriers. The TL is an expression of the "resistance factor" for beam penetration of a laser protective device. This is generally related by the threshold limit (TL) of the protective device, expressed in $W \cdot cm^{-2}$ or $J \cdot cm^{-2}$. It is the maximum average irradiance or radiant exposure at a given beam diameter for which a laser protective device provides adequate beam resistance. Thus, laser exposures delivered on the protective device at or below the TL will limit beam penetration to levels at or below the applicable MPE.

transmission. Passage of radiation through a medium.

ultraviolet (UV) radiation. Electromagnetic radiation with wavelengths of 180–400 nm (wavelengths shorter than those of visible radiation).

uncontrolled area. An area where the occupancy and activity of those within it are not subject to control and supervision for the purpose of protection from radiation hazards.

viewing window. A visually transparent part of an enclosure that contains a laser process. It may be possible to observe the laser processes through the viewing window(s).

visible radiation (light). The term used to describe electromagnetic radiation that can be detected by the human eye. Wavelengths that lie in the range 400–700 nm. Some standards may use 380–780 nm for the visible radiation range. ANSI Z136 uses 400–700 nm.

watt (W). The unit of power or radiant flux. 1 watt = 1 joule per second.

wavelength. The distance in the line of advance of a sinusoidal wave from any one point to the next point of corresponding phase (e.g., the distance from crest to crest or trough to trough).

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