Health Sciences Authority

Centre for Radiation Protection

Short Notes
On

Laser Radiation

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1 Differences between Ionising Radiation & Non-Ionising Radiation

Ionisation is an electrical process in which an electron is knocked out of its orbit. Ionising radiation is radiation that is energetic and capable of causing atoms and molecules in its path to split into positive and negative ions. Ionising radiation include alpha, beta and gamma rays that are arisen by the decay of radioactive substances and X-ray that is produced electronically by X-ray machines. Alpha and beta are particulate radiation while gamma and X-rays are electromagnetic radiation of wavelengths from 100 nm to 10^{-5} nm.

Alpha, beta & gamma rays are resulted from spontaneous re-arrangements within unstable nuclei but X-rays are produced by electrons jumping between orbits close to the nucleus or by electrons losing energy when passing through the strong electric field close to the nucleus. Unlike the radiation from radioactive sources, the X-rays can at anytime be "turned off" by merely disconnecting the high voltage.

Alpha and beta are sub-atomic particles while gamma and X-rays are electromagnetic rays similar to light. These radiations differ in their penetration abilities as follows: -

* Alpha radiation can be completely absorbed by a sheet of paper or a few cms of air,

* Beta radiation can be completely absorbed by a few cms of wood, glass, water or several meters of air,

* Gamma & X-ray radiation are difficult to be absorbed completely, but the intensity can be reduced significantly by a few mms of lead, or a few cms of concrete or brick, for low energy radiation and by 10 or more cms of lead or a meter or so of concrete or brick for high energy radiation.

Non-ionising radiation refer to the radiation that the energy is not capable in causing ionisation but is capable in causing other injuries to the body. It includes the electromagnetic radiation and fields with wavelengths greater than 100 nm and acoustic radiation and fields with frequencies above 16 kHz. Examples are microwave, ultraviolet, visible, infrared, laser and ultrasound radiation.

Non-ionising Radiation **Ionising Radiation**
wavelength μm

10^{10}	10^{7}	10^{3}	0.75	0.4	0.04	10^{-8}
RF	**microwave**	**infrared**	**visible**	**ultraviolet**		**X & gamma**

Electromagnetic radiation is created by oscillating electric charges. The frequency of oscillation determines the kind of radiation that is emitted. Electromagnetic radiation can be considered as a stream of particles called photons. Each photon has associated with it an amount of energy hv, where h is Planck's constant (6.626 x 10^{-34} Joule.sec or 4.1357 x 10^{-15} eV. sec). The frequency of the wave motion can be used to calculate the energy of the emitted photon; thus, radiation has a dual wave-particle character.

	Region	**Type of Radiation**	**Frequency**	**Wavelength**	**Photon Energy**
Ionising Radiation	Ray Region	Gamma rays	> 10^{19} Hz	< 0.03 nm	> 40 keV
		X-rays	3 x 10^{15} Hz to 10^{19} Hz	0.03 nm to 100 nm	12.4 eV to 40 keV
Non-Ionising Radiation	Optical Region	Ultraviolet	7.5 x 10^{14} Hz to 1.67 x 10^{15} Hz	100 nm to 400 nm	3.1 eV to 6.9 eV
		Visible	4.3 x 10^{14} Hz to 7.5 x 10^{14} Hz	400 nm to 700 nm	1.77 eV to 3.1 eV
		Infrared	3 x 10^{11} Hz to 4.3 x 10^{14} Hz	700 nm to 1 mm	0.00124 eV to 1.77 eV
	Wave Region	Microwave	300 MHz to 300 GHz	1 mm to 1 m	10^{-6} eV to 10^{-3} eV
		Radiowave	< 300 MHz	> 1 m	< 10^{-6} eV

The biological effects du to the non-ionising electromagnetic Radiation is very different from that of X-rays and gamma radiation. The effect is mainly the thermal effect and it has no cumulative effect. However, with sufficient energy, the non-ionising radiation can also cause injuries to the human body. For example, high power lasers can produce skin burn and eye injury, over exposure to ultraviolet radiation can cause skin cancer, exposure to extremely high intensity ultrasound can elevate the tissue temperature and create tiny bubbles of gas or cavities in the body.

2 Laser Radiation

a Physical characteristics

The word **"LASER"** is an acronym for "Light Amplification by Stimulated Emission of Radiation". Light that comes from a conventional light source radiates in all directions and in various wavelengths that reinforce or cancel each other. On the other hand, light from a laser beam travels in one direction in straight line and in a specific wavelength only; thus, the laser beam is a very narrow beam. Laser radiation may be released either as a pulse or a continuous wave radiation. Note that laser beams are not limited to visible wavelengths only. Though a laser beam produces only one wavelength, laser units can be designed over a wide range of frequencies, from infrared to ultraviolet regions.

b Laser Sources

Basically, a laser system consists of two accurately parallel reflecting-end-plates between which the active lasing material is placed, one plate being slightly transparent. Active lasing-material is pumped by exciting its atoms or molecules to an excited state. A light wave is then emitted when an excited atom falls from an excited-energy state to a lower-energy state. Light waves emitted parallel to the axis of the active lasing material are reflected back and forth between the two end-plates and stimulate other atoms or molecules to emit light wave of the same frequency. When amplification is great enough, a laser beam would pass through the partially reflecting end plate.

c Classification of Laser

The hazard classification specified for laser are defined by the output parameters, i.e. emission wavelength, emission duration, power output, and accessible emission levels (AELs) of laser radiation.

Class 1 laser systems are safe by virtue of their power output or engineering design. These lasers cannot be considered as hazardous even if all of the accessible laser radiation output is to direct to the eye's pupil or focus into one-mm spot on the skin for a day. These lasers are considered as non-risk lasers, or exempt lasers. The wavelengths could range from ultraviolet, visible to infrared region. Class I continuous visible laser should not have the accessible laser output of more than 0.39 microwatts.

Class 2 laser systems are those emitting visible laser radiation, in the wavelength range from 400 nm to 700 nm, in pulse or continuous wave. This is a class of low-power and low-risk lasers. These laser systems are normally not hazardous by virtue of normal aversion responses. They are not capable of causing any eye injury within the duration of a blink of 0.25 sec. For class 2 continuous visible laser devices, the power emitted should not exceed one mW, bar code scanner at the check out point in supermarket and laser pointer in class room are good examples for class 2 laser. Any low-risk laser devices, by virtue of enclosure, should have warning labels indicating "High-risk class when access panels are removed".

Class 3 laser systems are considered to be medium-power and moderate-risk laser. Generally, they do not present any diffuse reflection hazard, skin hazard for unintentional exposure, or fire hazard. These lasers could present a serious potential eye injury resulting from intra-beam viewing of the direct beam and specula reflections. Class 3 laser can be further sub-divided into two subcategories, namely, class 3a and class 3b lasers.

I Class 3a lasers are capable of emitting visible and/or invisible laser radiation with the maximum accessible emission levels as specified. As for visible Class 3a laser d vices, they operate in a power range of 1 -5 mW, which have irradiance in the emergent beam of not more than 25 W/m^2. This class of laser are not capable of damaging the eye because of the person's normal aversion response to bright light, unless the radiation is stared at for a long time, or unless binoculars or optical instruments are used. Many construction alignment lasers fall into the class 3a category.

II Class 3b lasers are medium-power and moderate-risk laser devices that are capable of emitting ultraviolet, visible or infrared laser radiation with specified maximum accessible emission levels. It can be in continuous wave or pulsed mode and operating in a power of 500 mW or less for emission duration of longer than 0.25 sec, or a radiant exposure of 100 kJ/m^2 or less for emission duration shorter than 0.25 sec. These lasers are capable of causing accidental injuries by exposure from the direct or specularly reflected beam. Diffuse laser beam reflections from class 3b are not hazardous, but may be so if focused to eyes with optical instruments. Therapeutic, acupuncture, bio-stimulation lasers, military laser range finders and designator are all under class 3b lasers.

Class 4 lasers are high-power and high-risk lasers that are capable of emitting ultraviolet, infrared or visible laser radiation at levels exceeding the accessible emission levels for class 3b. The average power output of 500 mW or greater for periods longer than 0.25 sec, or a radiant exposure of 100 kJ/m^2 within an exposure duration of 0.25 sec or less. These lasers can produce a hazardous direct or specularly reflected laser beam. A potential fire and skin burn hazard exist as the possibility of hazardous diffuse reflections occurs.

d Laser applications

Forty three years after Einstein first introduced the concept of stimulated emission of radiation by atomic systems in 1917, the first working laser, ruby crystal laser, was produced in 1960.

I Industrial

Common high-power industrial lasers are,

* Industrial cutting
* Drilling, welding
* Marking
* Engraving
* Micro-machining
* Communications field
* Entertainment lasers

Other low-power industrial lasers are,

* Construction alignment lasers
* Dredging
* Tunnelling, pipe laying
* Bridge building
* Military applications
* Scanners for deciphering coded package markings
* Low power Entertainment laser

II Medical

High-power medical lasers are used in,

* Surgery
* Excision of malignant or non-malignant tissues
* Plastic surgery
* Removal of birthmarks
* Obstetrics and gynaecology
* Burning away warts
* Photo-coagulator for torn retinas by ophthalmologist

The low power medical lasers and they are,

* Acupuncture lasers
* Physiotherapy lasers
* Cosmetic lasers

III Research

Lasers are also used in Singapore for research and educational purposes. Most of the lasers are less than 5 W and they can be as high as 1000 W, i.e. class 4 CO_2.

e Laser radiation hazards and its exposure limits

Ocular Exposure to Laser Radiation

The main concern is with the eye damage, as it is capable of increasing the laser light intensity many thousands of times by its focusing power. Parallel rays of a laser may be focused to a point image by the eye while rays from a conventional lamp can produce a sizeable and less dangerous image at the retina. Light from a laser entering the eye is concentrated 100,000 times at the retina. Thus, the eye is, by far, the organ of the body most subject to damage.

Skin Exposure to Laser Radiation

Note that injury to skin is seldom of concern except in dealing with very high-powered lasers. However, with ever increasing laser intensities encountered, skin damage is becoming a concern to the laser operators.

Exposure limits

The unit used for describing the radiation exposure from laser is completely different from that for ionising radiation exposure. The units are Watts or milliwatts for laser power or W/m^2 or mW/cm^2 for laser intensity. Laser operators must note that the exposure limits should be used only as guidelines for controlling human exposure to laser radiation and they should not be regarded as thresholds of injury or as sharp demarcations between "safe" and "dangerous" exposure levels. Exposure at levels below the ELs should not result in adverse health effects.

f Safety guides against laser radiation

(a) Laser radiation should be discharged in a background that is non-reflective and fire resistant.

(b) The area should be cleared of personnel for a reasonable distance on all sides of laser beam.

(c) Warning sign should be attached to laser equipment in a conspicuous location indicating the potential eye hazard associated with laser.

(d) Looking into primary laser beam should be avoided at all times, and equal care should be exerted to avoid looking at specula reflections of the beam, including those from lens surfaces.

(e) Avoid aiming laser with eye and prevent looking along the axis of the beam, which increases the hazard from reflections.

(f) Laser work should be carried in areas of high general illuminations to keep pupils constricted; thus, limit energy that might inadvertently enter the eyes.

(g) Laser radiation workers should be instructed on potential eye hazards and the importance of limiting unnecessary exposure. They should receive pre-employment, periodic and final eye examinations.

(h) Safety eyewear designed to filter out specific frequencies characteristic of the system affords protection, but it may only be partial.

(i) Binoculars or aiming telescopes should not be used to view direct beam or reflected beam from mirrors unless the beam intensities are greatly below the safe levels. If necessary, a filter having sufficient optical density should be placed in the optical path of telescope for such situations or adequate laser protective eyewear is worn by the operator.

As high power lasers are capable of cutting and burning, thus, only the trained and qualified persons are allowed to use. For the use of low power lasers, it can also cause injury to the eyes if they are handled and used incorrectly by untrained personnel. Hence, there is a need to restrict its users to trained personnel only.

3 The Radiation Protection Act, 1991

The Radiation Protection Act was enacted to regulate, by means of licensing and penalty, the importation, manufacture, sale, transport, keeping and use of radioactive materials and irradiating apparatus.

To ensure the safe use of certain potentially hazardous non-ionising (NIR) devices in Singapore, the Radiation Protection Act 1973 was repealed in 1991. The devices now under control are high power lasers, entertainment lasers, ultrasound, microwave ovens, sunlamps, X-Ray machines and radioactive materials. The activities requiring licences include manufacture, sale, keep, use, importation and exportation of devices.

The Radiation Protection (Ionising Radiation) Regulations 2000

This set of regulations was first published and came into operation on 1 Sep 1974. Due to new the development in the field of radiation protection and the new recommendations of the International

Commission on Radiological Protection under ICRP Publications 60 and 61, the Regulations was amended, updated, re-arranged and published as Radiation Protection (Ionising Radiation) Regulations 2000 on February 2000.

The Radiation Protection (Transport of Radioactive Materials) Regulations 2000

This set of regulations was first published as The Radiation Protection (Transport of Radioactive Materials) Regulations 1974 and came into operation on 1 Sep 1974. To be in line with the latest revision of the International Atomic Energy Agency's (IAEA) regulations on the transport of radioactive materials (IAEA Safety Standards Series No. ST-1, 1996 Edition), this set of regulations was amended, updated, re-arranged and published as Radiation Protection (Transport of Radioactive Materials) Regulations 2000 on February 2000.

4 Radiation Protection (Non-Ionising Radiation) Regulations 1991

The first set of regulations formulated under the new ct to impose detailed requirements, in dealing with Non-ionising Radiation irradiating apparatus, was published on 1 Nov 91. The new Act and new Regulations came into operation on 1st February 1992. It applies to the following NIR irradiating apparatus:

a Ultraviolet sunlamps

Sunlamp means ultraviolet lamp or apparatus incorporating one or more ultraviolet lamps intended for irradiation of any part of living human body, by ultraviolet radiation with wavelengths in the air between 180 nm to 400 nm, to induce skin tanning or other cosmetic effects.

b Microwave ovens

Microwave oven means a device designed to heat, cook or dry food or material within a cavity through the application of microwave energy with the frequency ranges from 890 MHz to 6 GHz and is used in an industrial establishment, a commercial establishment, a restaurant, a cafeteria, in or with a vending machine, or in the home.

c Medical and industrial ultrasound apparatus

Ultrasound apparatus means medical diagnostic apparatus, medical therapeutic apparatus and industrial apparatus designed to generate and emit ultrasonic power at acoustic frequencies above 16 kHz.

d Magnetic resonance imaging (MRI) Apparatus

Magnetic resonance imaging apparatus means any medical diagnostic apparatus designed to emit magnetic field and RF radiation for the purpose of imaging or spectroscopy of human body or both.

e Entertainment lasers

Entertainment laser means any laser, laser facility or mobile laser system designed for used in laser light shows.

f High power lasers

High power laser means any industrial and medical laser apparatus from Class 3b and Class 4 based on the classification set out in Regulations. For a person to engage in any laser radiation work, he must be at least 18 years old, has been adequately trained, has special knowledge in the safe use of laser and holds a licence authorising him to operate the lasers. In addition, a licence to use Class 4 medical lasers may be granted to registered medical practitioners and registered dentists only.

Types of licences related to lasers are

* Licence to manufacture, possess for sale or deal in lasers
* Licence to keep or possess for use of lasers
* Licence to operate or use lasers
* Licence to import or export lasers

In Singapore, any one found using class 3b & 4 lasers without licence would be charged for violating the Act and could be fined up to maximum of not than $10,000 or imprisonment for a term of not exceeding 12 months or both.

Types of licences Issued by CRP for manufacture, sale, possession and use of Non-Ionising Radiation apparatus

	Application Reference	Fee
N1	Licence to manufacture or deal with Microwave ovens, UV sunlamps, medical and industrial ultrasound devices, Magnetic Resonance Imaging (MRI), class 3b & 4 high power medical and industrial lasers and all classes of entertainment lasers	**$210** per annum
N2	Licence to keep or possess for use of high power (Power > 1 Watt) industrial ultrasound cleaners, ultrasound welders, ultrasound cutter etc, medical diagnostic ultrasound, therapeutic ultrasound, surgical ultrasound, Magnetic Resonance Imaging (MRI), class 3b & 4 high power medical and industrial lasers and all classes of entertainment lasers	**$155** per annum
N3	Licence to use class 3b & 4 high power medical and industrial lasers and all classes of entertainment lasers	**$105** per annum
N4a	Licence to import Microwave ovens, UV sunlamps, medical and industrial ultrasound devices, Magnetic Resonance Imaging (MRI), class 3b & 4 high power medical and industrial lasers and all classes of entertainment lasers	**$ 40** per consignment
N4b	Licence to export high power (Power > 1 Watt) industrial ultrasound cleaners, ultrasound welders, ultrasound cutter etc, medical diagnostic ultrasound, therapeutic ultrasound, surgical ultrasound, Magnetic Resonance Imaging (MRI), class 3b & 4 high power medical and industrial lasers and all classes of entertainment lasers	**$ 40** per consignment