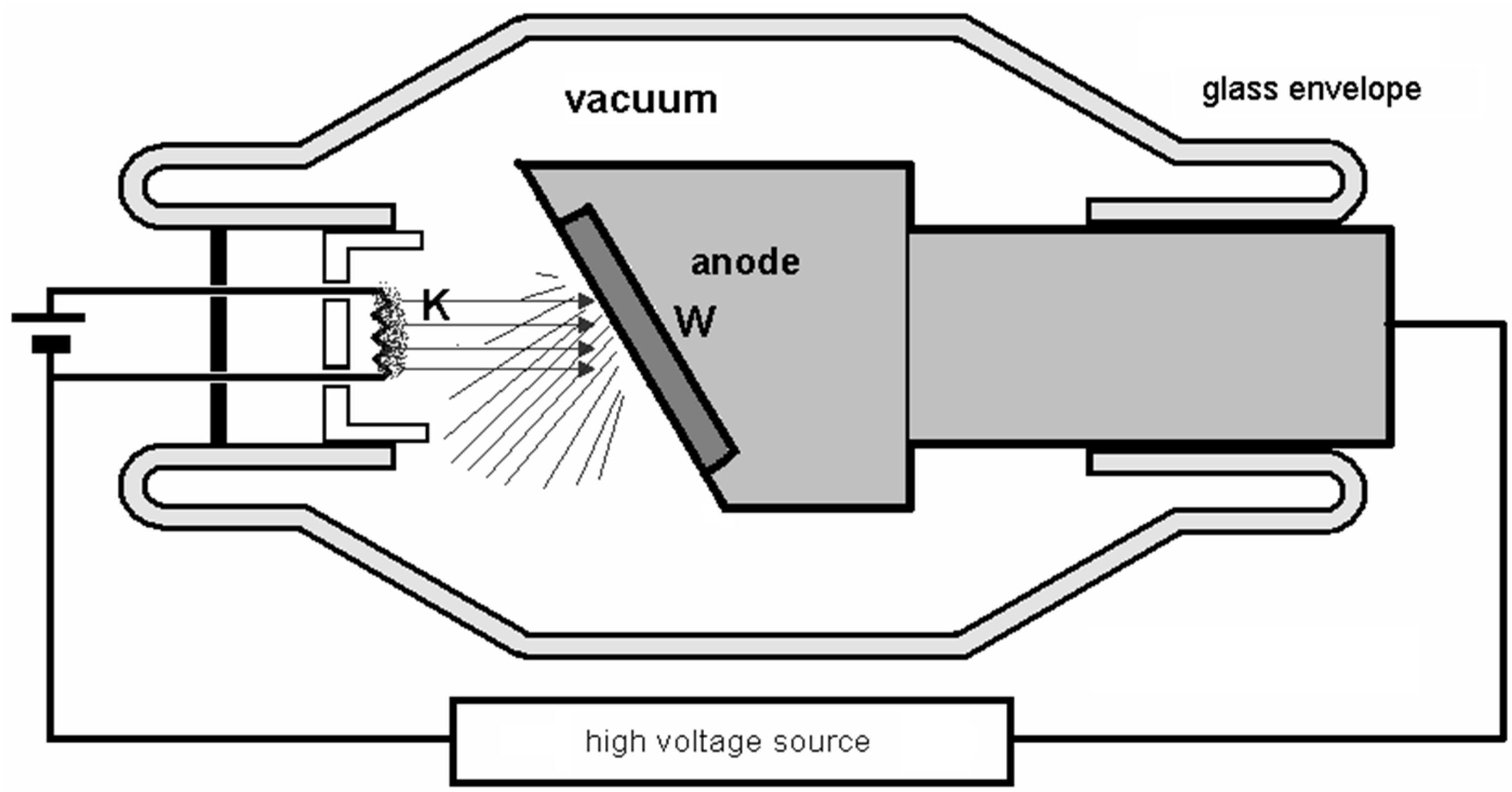
X-rays and Laser

Daniel Vlk
Institute of Biophysics

Origin of X-rays

- X-rays are beams of electromagnetic radiation which originate in atomic electron shells. Wavelength <10nm.
- They are formed by photons of very high energy (substantially higher than the energy of ultraviolet light photons). In practice, they are produced in X-ray tubes – evacuated glass tubes involving two electrodes – the anode and the cathode.
- Electrons escape from the hot cathode surface (thermoemission of electrons), and then they are rapidly accelerated in the space between the hot cathode and the (cold) anode by very high electric voltage (e.g. 150,000 volts).
- The energy of electrons striking the anode is given by the term $\frac{1}{2}m.v^2$ which is equal to their original potential energy Ue.


vacuum
glass envelope
anode
W
K
high voltage source

Origin of X-rays

- Subsequently, these electrons are suddenly decelerated in a tungsten (W) target which is a part of the anode. It means that their kinetic energy is transformed into X-ray and heat energy.
- However, on average, only a small part (less than 1 %) of this energy is transformed into high energy X-ray photons. More than 99 % of their energy is transformed into heat. In the rare case of total electron energy transformation into a single X-ray photon, the energy of the photon is:

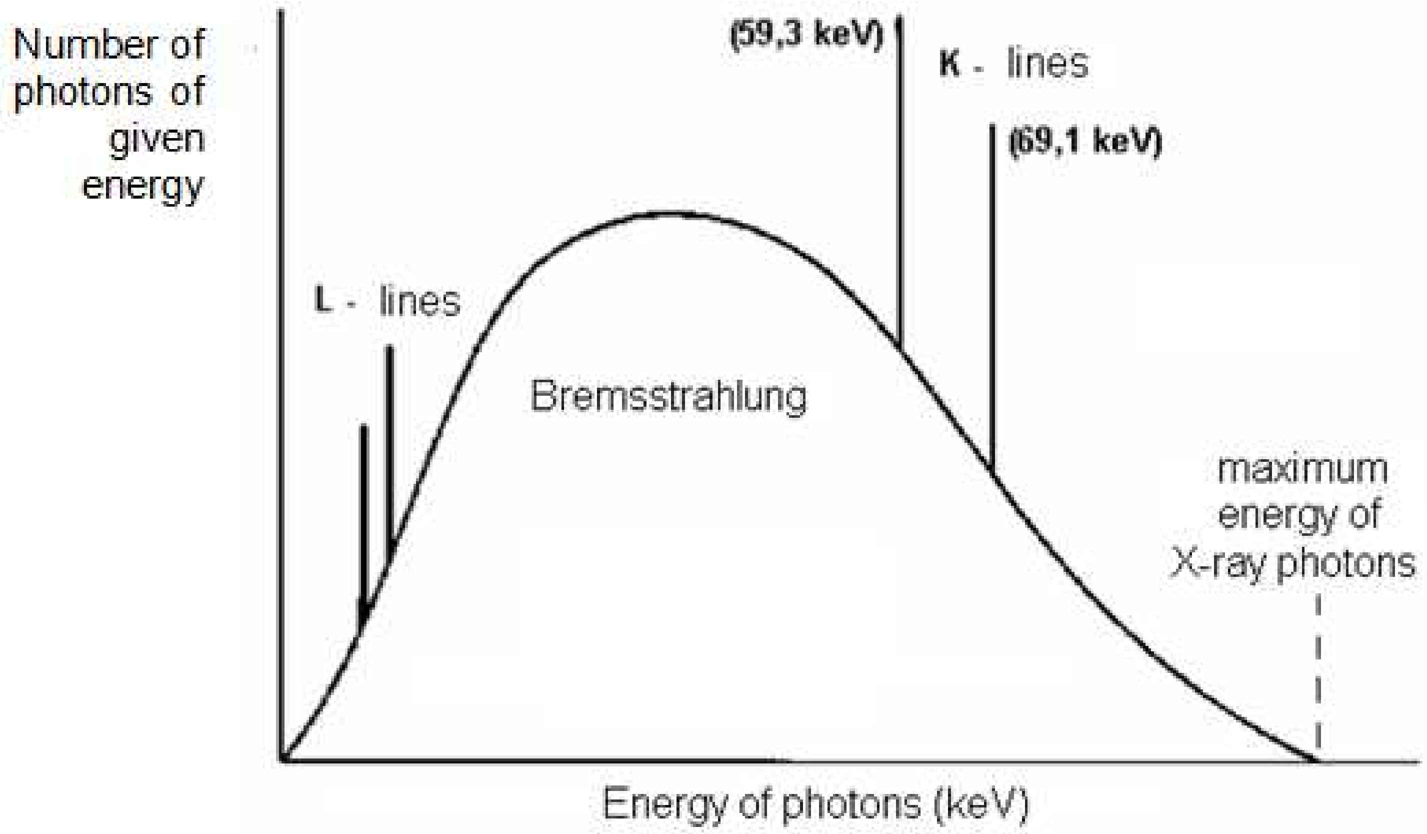
$$E = hf_{max} = \frac{1}{2}mv^2 = Ue = \frac{hc}{\lambda_{min}} \qquad (f = c/\lambda)$$

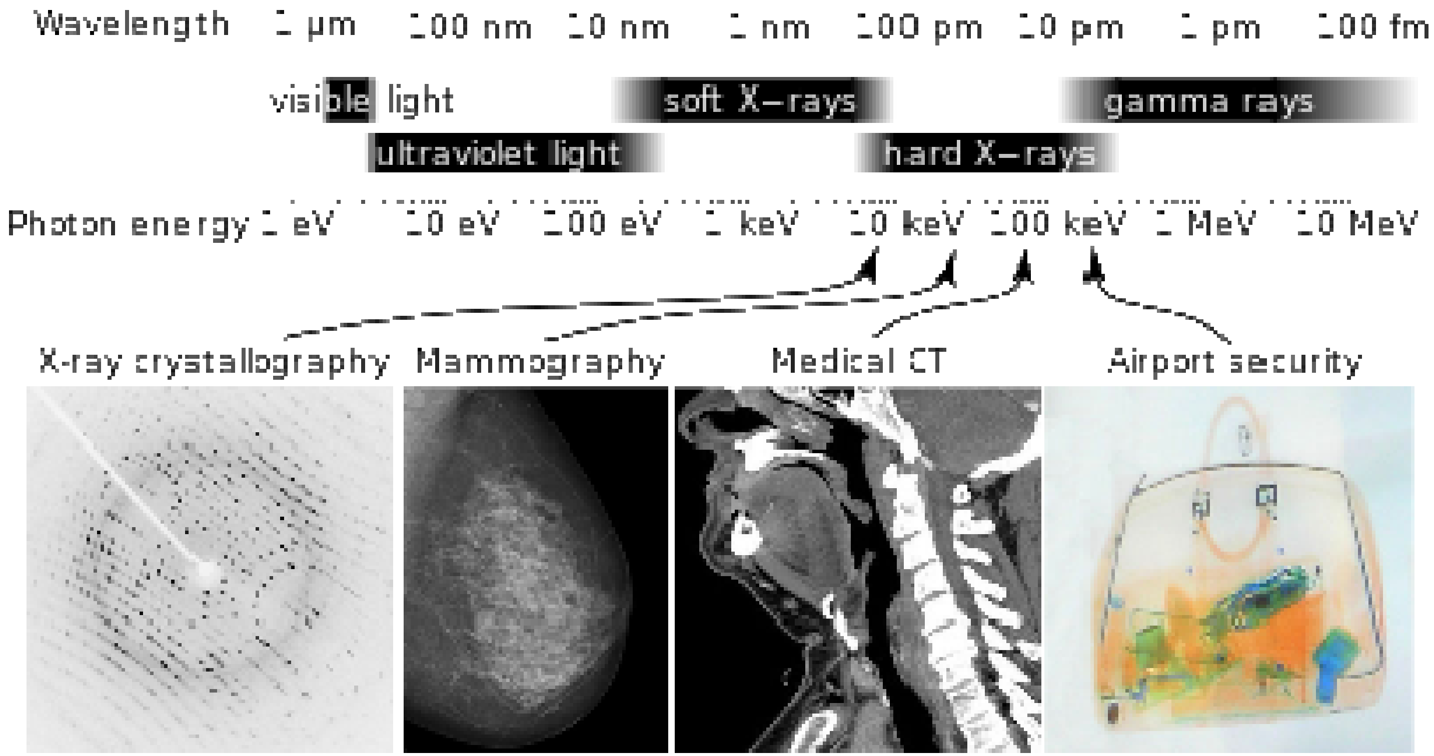
where hf_{max} is the maximum energy of the liberated photon. Such photons possess maximum possible frequency f_{max} or the shortest possible wavelength λ_{min}.

Origin of X-rays

- The energy spectrum of these X-rays is continuous.
- The X-rays produced in this way are called "**Bremsstrahlung**" (i.e. deceleration radiation) which is a German word used in honour of the German physicist W.C. Roentgen, the discoverer of X-rays.
- X-ray photons can be also produced by jumps of electrons from outer to the innermost shells of some heavy atoms.
- There are vacancies (unoccupied sites) formed by impact of accelerated electrons, which must be filled immediately by some other electron.
- The spectrum of X-rays produced in this way consists of lines representing discrete energies of photons. This is the **characteristic radiation**.

Origin of X-rays




Wavelength
1 μm
100 nm
10 nm
1 nm
100 pm
10 pm
1 pm
100 fm
visible light
ultraviolet light
soft X-rays
hard X-rays
gamma rays
Photon energy
1 eV
10 eV
100 eV
1 keV
10 keV
100 keV
1 MeV
10 MeV
X-ray crystallography
Mammography
Medical CT
Airport security

Laser

- ***L**ight **A**mplification by **S**timulated **E**mission of **R**adiation*.

- The first ruby laser was constructed by T.H. Maimann in 1960. Main parts of a laser:
  - **active medium**
  - **optical resonator**
  - **source of excitation energy**

Laser

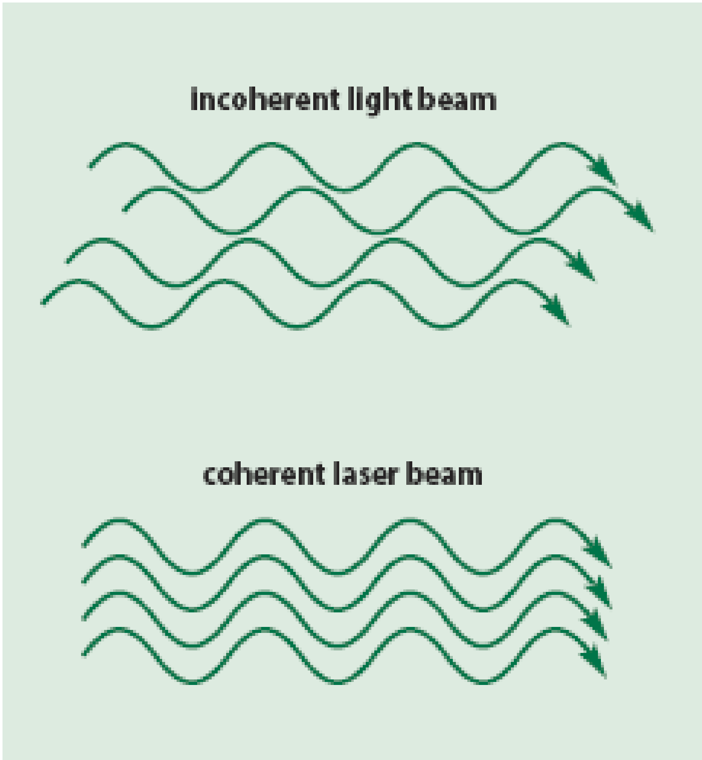
- Principle of the laser: alternating excitation and deexcitation.
  - Electrons of the atoms of the active medium are excited by the source energy („optical pumping“).
  - Thereafter they are deexcited by a stimulating photon, new photons of the same energy arise and the effect is repeated – amplification occurs.
  - In the so-called three-level laser, the third energy level is broad, thus it is not necessary to use monochromatic (i.e. monoenergetic) light for optical pumping. Because of small energy difference between the second and third energy level, the electron transition to the second energy level is spontaneous („thermal“) – electrons are waiting for the stimulating photon there.

Lasers

- **Solid l.** (compact, semiconductor): ruby laser (694,3 nm), neodymium (1,06 µm),
- **Semiconductor l.** – based on the principle of electroluminescence.
- **Liquid l.** An organic dye solution is used as active medium. Advantage: can be tuned to different wavelengths (from near IR, VIS to UV range).
- **Gaseous l.**. Important for medicine. Helium-neon laser (1,06 µm) and ion lasers (argon and krypton). CO_2-N_2-He-laser etc.
- Plasma l. Active medium is plasma, fully ionised carbon – irradiates soft X-rays.
- Lasers can operate in two modes: **continuous** and **pulsed**
- Laser power ranges from 10^{-3} to 10^{4} W. Low-power lasers (soft-lasers) are used mainly in physical therapy. High-power lasers are used as surgical tools (laser scalpel).

Effects of laser radiation

- Laser light is monochromatic and coherent. This allows us to concentrate the laser beam on a small area and to reach a high output density. The laser beam can be guided by mirrors, lenses, or optical fibres.



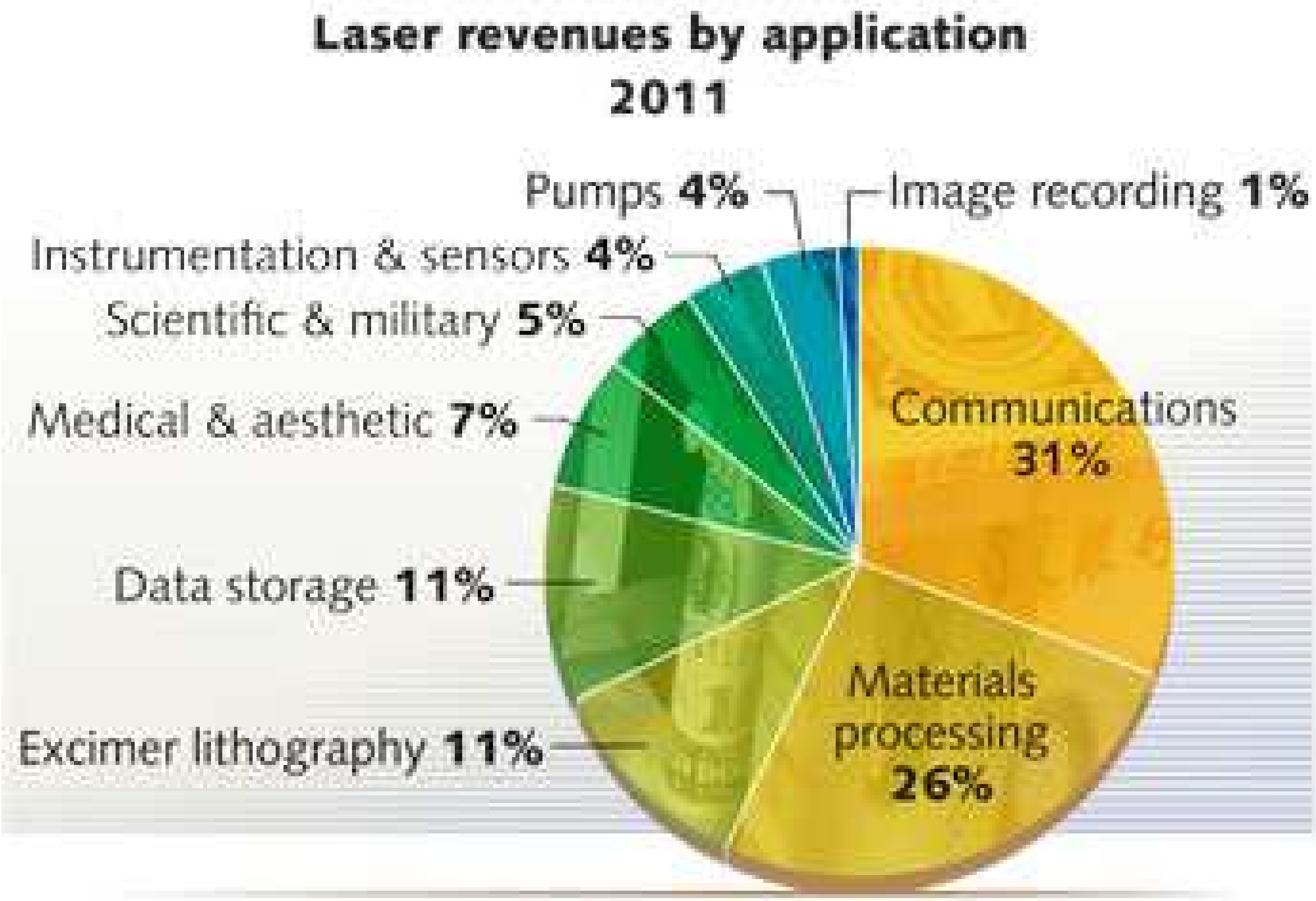
Effects of laser radiation

- Thermal effects depend on the power density of light and its wavelength. They are exploited mainly in surgery and microsurgery.

- Non-thermal effects are typical for soft-lasers, they depend little on the wavelength – based on a molecular action mechanism (action on enzymes of the respiratory chain, enhancement of mitochondrial DNA replication, enhancement of enzyme activity).

- Laser light also has a photodynamic effect – chemical changes of inactive substances irradiated by laser light of certain wavelength can lead to formation of (e.g. biologically) active derivatives.

Laser applications



Soft-laser application

- Surface applications – short wavelength, deep applications – long wavelength (near IR).
- *laser pens* are the simplest devices, based on laser diodes, fed by batteries, constant power setting.
- **Small lasers** (pocket) with exchangeable probe, different frequency modes are possible.
- **Tabletop lasers** – user comfort, many functions and applications.

High-power laser application

General surgery:

A laser can serve as an optical lancet cutting without contact. The blood vessels are coagulated and the cut practically does not bleed.

Ophthalmology:

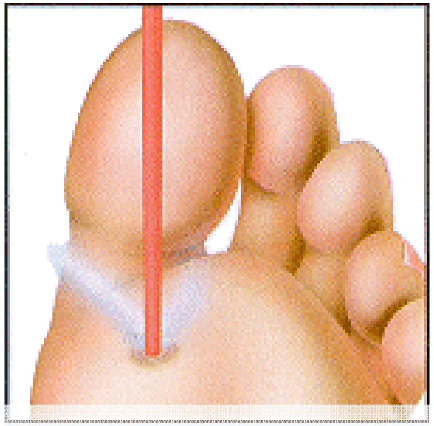
Besides being the light source of many optical instruments used for examination, the main use is photocoagulation of retina and photoablation of cornea to correct re

In **dentistry,** in oral surgery and endodontics, and for precise preparation of the tooth enamel and dentine.

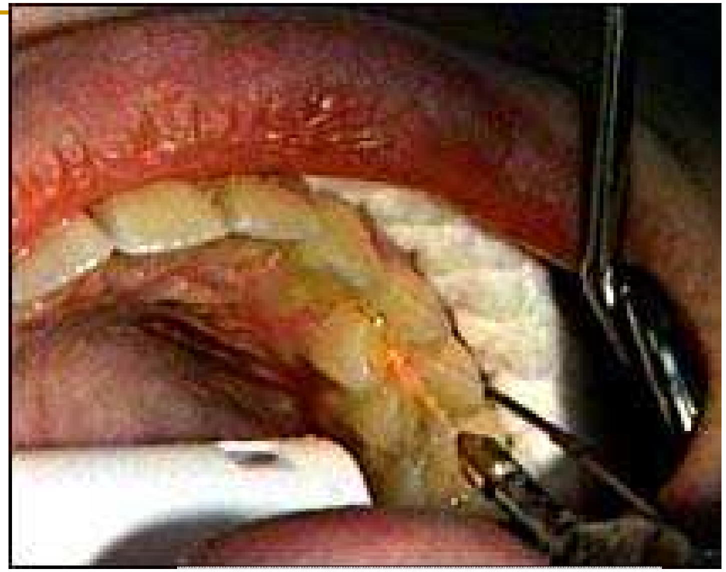
Dermatology - the main applications are photocoagulation of varicose veins, wart removal, skin lifting, depilation and tattoo removal.

Laser applications - medical

Surgical laser unit



removal of warts



caries removal

Face lifting

Lasers

- devices: CT, MRI, radiotherapy systems, laser surgery, eye-lens corrections, DVDs etc
- bioeffects: thermal and photochemical damage to skin, retina as eye-lens can focus laser to a very intense point on the retina, cornea burn
- Laser Protection Adviser (LPA) and Laser Protection Supervisors
- laser controlled areas
- local rules
- appropriate training
- protective eye-wear
- Maximum Permissible Exposure levels

Laser Classes

- classes 1 - 4 in increasing power
- Class 1: Inherently safe (max permitted limit cannot be exceeded) because laser is very low power or housed in an enclosure that does not allow harmful levels of exposure (eg laser printer, CD drive)
- Class 2: low power where safety is afforded by blink mechanism of eye (eg laser lecturing pointer)
- Class 3A and 3B: direct beam viewing could be hazardous
- Class 4: high power devices. Direct beam and reflections hazardous.