L18 LASER IN MEDICINE

What is the laser?

LASER is an acronym for Light Amplification by the Stimulated Emission Radiation.

The stimulated emission of light is the crucial quantum process necessary for the operation of a laser.

Laser Spectrum

Lasers operate in the ultraviolet, visible, near infrared and far infrared regions of the spectrum.

Characteristics of Laser Light

- A laser is a unique light source that emits a narrow beam of light of a single wavelength (monochromatic, directional and coherence)

The combination of these three properties (monochromatic, directional and coherence) makes laser light focus 100 times better than ordinary light.

- **Monochromatic**

Property of laser light means it is all one wavelength.

Concentrate in a narrow range of wavelengths (one specific color). Means it is all one wavelength.

- **Directional**

Bulbs Light vs. Laser Light

- ☒ Light from bulbs are due to spontaneous emission

  Laser light are due to Stimulated Emission
- ☒ Light from bulbs are multidirectional

  The directional λ of laser, a very tight beam that is very strong and concentrated. means that the beam spreads very slowly

W is the waist, or the minimum width of the beam inside the laser cavity - NOT ZERO!

- **Coherence**

All the emitted photons bear a constant stage relationship with each other in both time and phase

Coherent: If the phase of a light wave is well defined at all times (oscillates in a simple pattern with time and varies in a smooth wave in space at any instant).

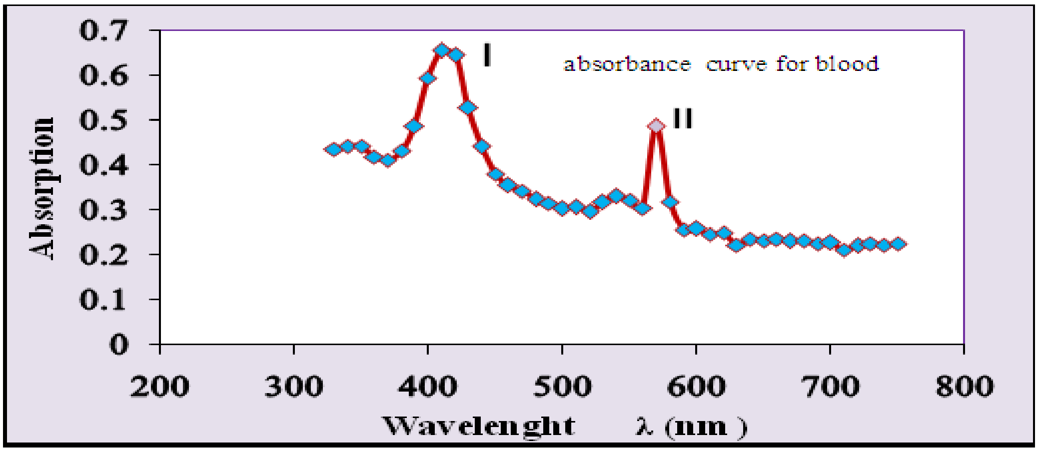
Example: a laser produces highly coherent light. In a laser, all of the atoms radiate in phase.

Incoherent: the phase of a light wave varies randomly from point to point, or from moment to moment.

Example: An incandescent or fluorescent light bulb produces incoherent light. All of the atoms in the phosphor of the bulb radiate with random phase.

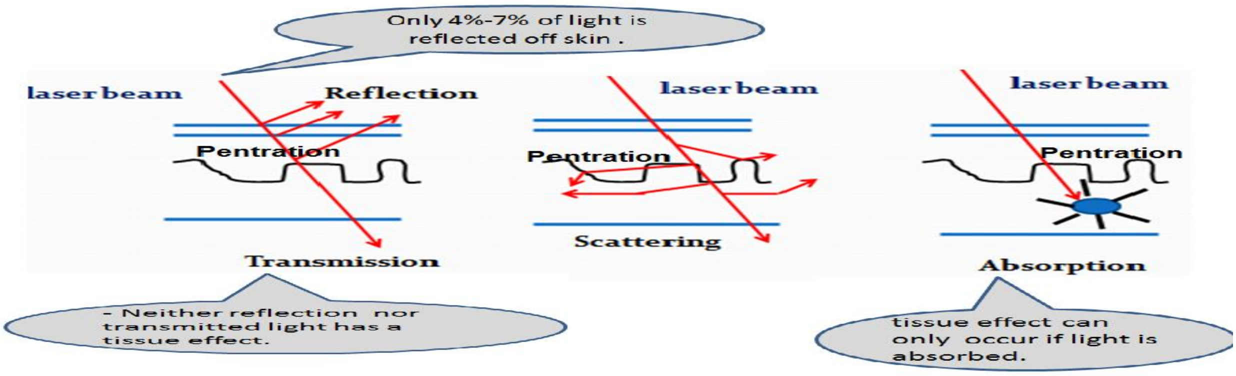
Lasers in Medicine Laser use in the field of medicine is large and steadily growing. This growth is based on the versatility of laser light. The characteristics of laser light are defined by its wavelength, pulsed or continuous wave operation as well as its average power.

- Primary use: to deliver energy to tissue
  - The laser wavelength used should be strongly absorbed by tissue
  - Good absorption in the blue-green region of the spectrum (400-600 nm)(absorbance curve for blood is shown in the figure below) it is better than the long wavelength (700 nm)
  - Less efficient in red/infrared



Interaction of laser with tissues

When a laser beam strikes the living tissues, there are four possible interactions (absorption, transmission, reflection and scattering)



Like normal light, laser light can interact with tissue in four basic ways as follows:

(1) Reflection: some light reflects back off the surface, its energy neither penetrating nor interacting with tissue.

(2) Transmission: some (light) may be transmitted through tissue, albeit unchanged as if transparent to the laser beam and without interaction between the incident beam and the tissue.

(3) Scatter: some light may penetrate the tissue and be scattered without causing a noticeable effect on the tissue. Scattering causes some lessening of light energy with distance, together with distortion in the beam,

(4) Absorption: some light may be absorbed into a component of the tissue, whereby there will be transference of energy to the tissue, i.e. the incident energy of the beam is attenuated by the medium and transferred into another form.

Therefore, the tissue effect can only occur if light absorbed

Laser energy directed at human tissue causes a rapid rise in temperature and can destroy the tissue. The amount of damage to living tissue depends on how long the tissue is at the increased temperature.

When laser light absorbent the following effects accrues: -

1-Thermal effect of laser beam

- ✓ increases (5- 10) °C Cell injury, subsequent inflammation and repair.
- ✓ Below 100 °C denature macro-molecules, for instance, by breaking Van der Waal's bonds.
- ❖ above 60° C most proteins are denatured.
- ❖ above 70° C DNA also denatured.
- ✓ Over 100° C intracellular water exceeds the boiling point and vaporization → fast increase in pressure → effected in cell & blood vessel.
- ✓ Increase in heat above 100° C → desiccation &charring

2- Mechanical effects

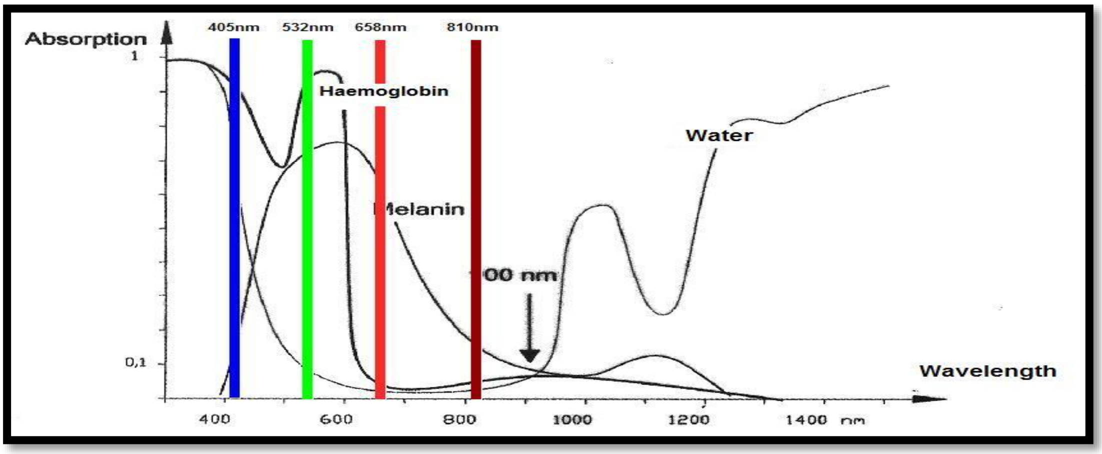
Laser cause photomechanical effect.

When pulse duration is shorter than the TRT (thermal relaxation time) of the target , → thermos elastic → expansion because of spatially localized heating → acoustic wave damage surrounding structures.

TRT: Time taken for 50% of heat energy to be conducted away from target tissue.

3- Selective photothermolysis effect

The concept of selective photothermolysis by choosing a wavelength absorbed by the target tissue, it should be possible to select a pulse duration and fluency that will selectively damage the target (chromophore in the skin (blood, melanin) without causing a change in adjacent tissues. Therefore, Red lasers are used in surgery because it is not absorbed by blood



- **Primary Damage Mechanisms:**
  - Red/Infrared - Primarily heating
    - Tissue can stand 70°C for 1 sec, 100°C destroys tissue.
  - Blue/Green - Photochemical
    - Example: 24 W/cm^2 1064 nm Nd:YAG produces some heat damage to the retina. 0.03 W/cm^2 411.6 nm Ar^+ produces the same degree of damage.

Light-tissue effects can be grouped in:

a) Photo thermal Reactions:

Laser light absorbed by chromophores (Tissue elements that absorb a particular wavelength or spectrum of light energy to a high degree) in the tissue is converted into heat.

A typical application of photo thermal reactions is:

1. **Photocoagulation: the laser light is absorbed by hemoglobin to stop bleeding or to seal blood vessels, the heating a blood vessel to point where the blood coagulates and blocks the vessel.**
2. **In ophthalmic surgery.**
   In eye the retina may become detached from the choroid owing to disease, injury, or degenerative changes. The laser is primarily used for photocoagulation of the retina, the heating blood vessel to point where the blood coagulates and blocks the vessel.
3. **Thermal ablation when laser light vaporizes tissue water for tissue cutting.**

- **This interaction requires laser solutions that have high average power and a wavelength that matches the absorption levels of target tissue.**

b) Photochemical Reactions:

Photons absorbed by tissue molecules. Excited molecules can undergo chemical reactions.

1. **A prominent example is Photodynamic therapy (PDT) where a photosensitive drug is administered. Using specific wavelengths enables applications such as selective photo thermolysis. Tattoo removal is an example of this.**

- **This interaction requires laser solutions that have high average power and a wavelength defined by molecule absorption.**

2. **Photoablation: Laser light is used to break the molecular bonds in the tissue.**

Key applications include

- ✓ **Ophthalmology where UV laser light is used for refractive surgery of the cornea,**
- ✓ **Lithotripsy where high energy laser pulses are used to generate plasma and shock waves that can break up kidney stones.**
- **Typical laser solutions operate in pulsed mode for high peak power and, depending on the type of tissue, have UV to NIR wavelengths**

Laser effects on tissue depend on

- **The power density of the incident beam,**
- **Absorption of tissues at the incident wavelength,**
- **Time beam is held on tissue,**
- **The effects of blood circulation**
- **Heat conduction in the affected area**

Important parameters

- **Optical properties of the tissue absorption & scattering coefficients**
- **Thermal properties of the tissue: thermal capacity & thermal conductivity**

Laser parameters

1. **Wavelength**
2. **Power density.**
3. **Exposure time.**
4. **Fluence.**
5. **Pulse duration.**
6. **Focused spot size.**
7. **Repetition rate (for pulsed wave).**

Applications of laser in medicine

The laser is routinely used in clinical medicine not only in ophthalmology. Its effectiveness in treating certain type of cancer, its usefulness as a bloodless knife for surgery. The use of endoscopes in diagnosis, Photodynamic (PDT) is an alternative to surgery for cancer.

Most common uses of lasers

- **Surgery : "bloodless" knife, sealing of blood vessels, burning of diseased tissue**
- **Opthalmology: Photocoagulation - sealing of blood vessels in the retina, to repair tears, holes which occur prior to retinal detachments**

Type of medical laser

Lasers used in medicine include as principle any type or laser design, but especially:

CO_2 lasers, used to vaporize tissue, diode lasers, dye lasers, excimer lasers, fiber lasers, gas lasers, free electron lasers, Semiconductor diode lasers