The Abdus Salam International Centre for Theoretical Physics

2443-28

Winter College on Optics: Trends in Laser Development and Multidisciplinary Applications to Science and Industry

4 - 15 February 2013

Laser Safety

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Lasers Safety

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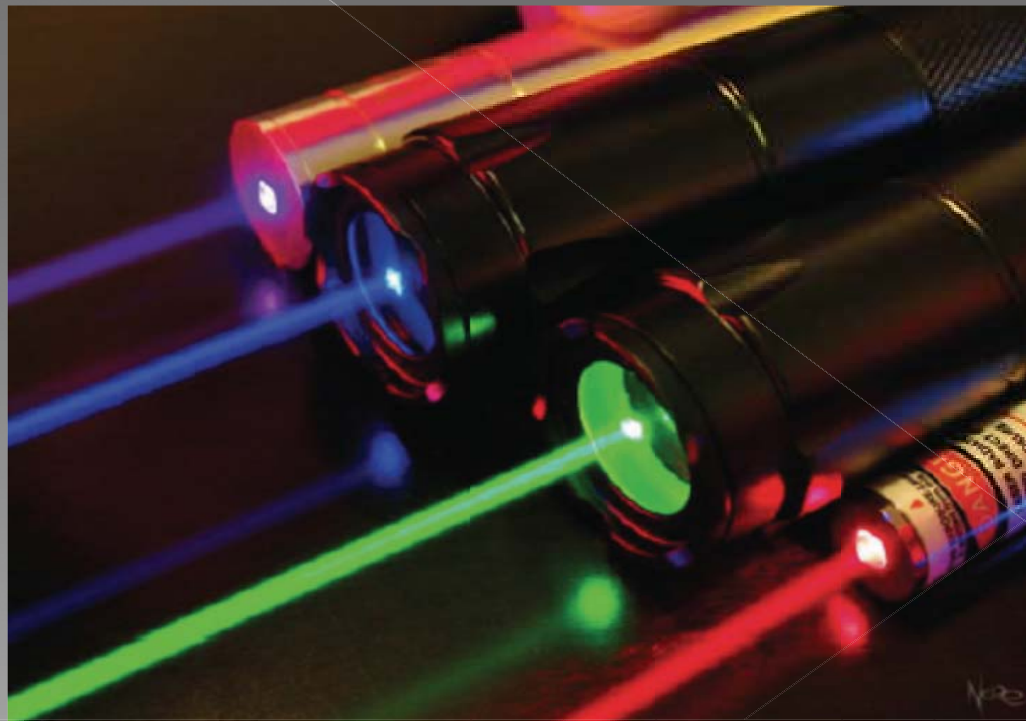
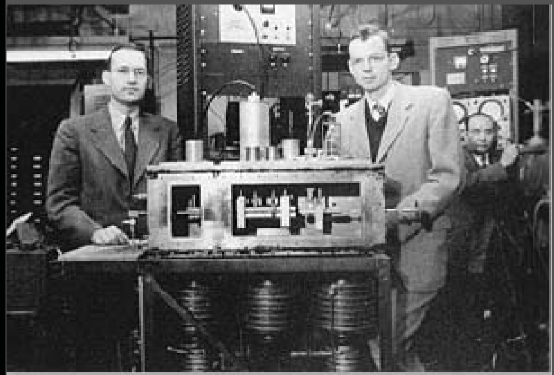


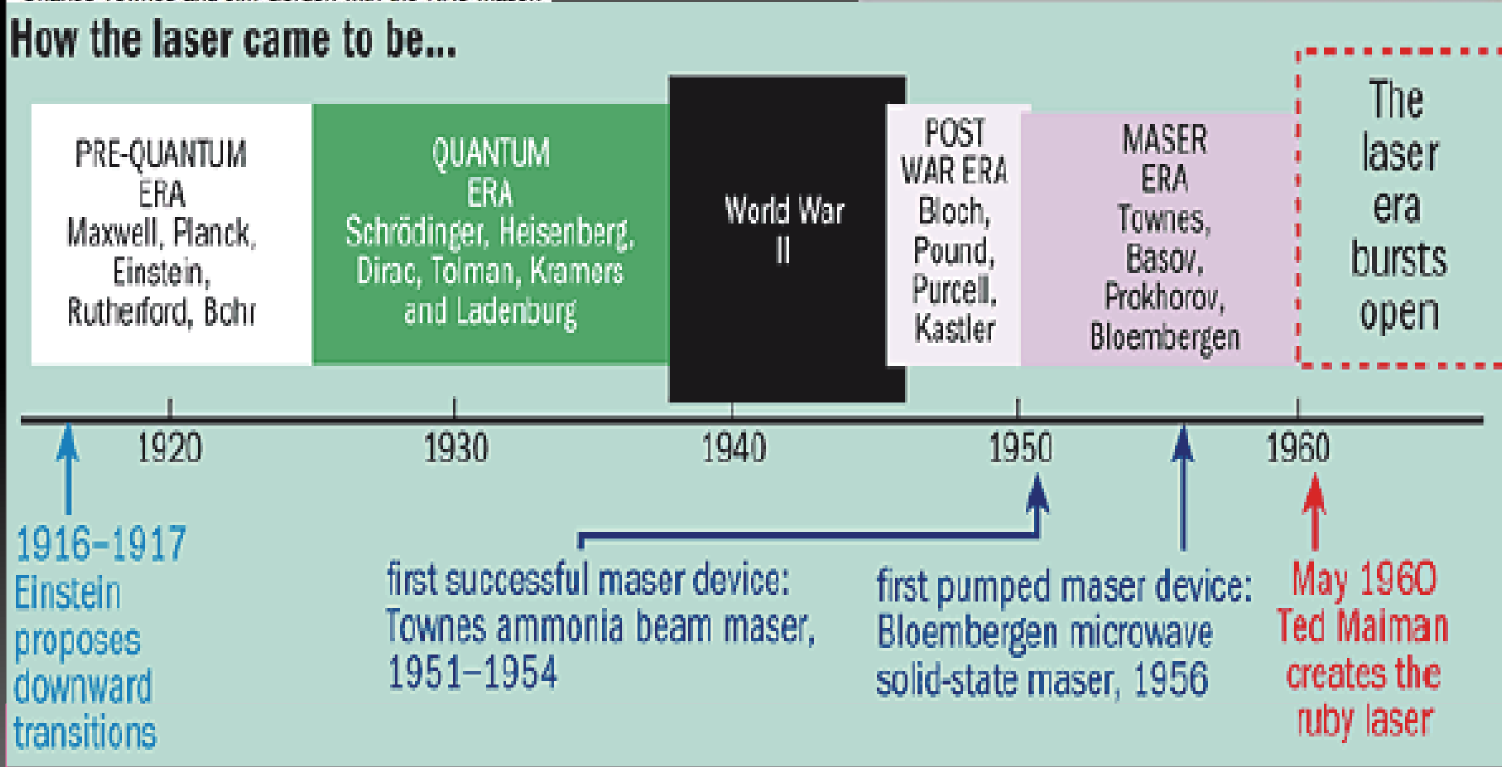
Outline of Talk

1. Beginning
2. Middle
3. End

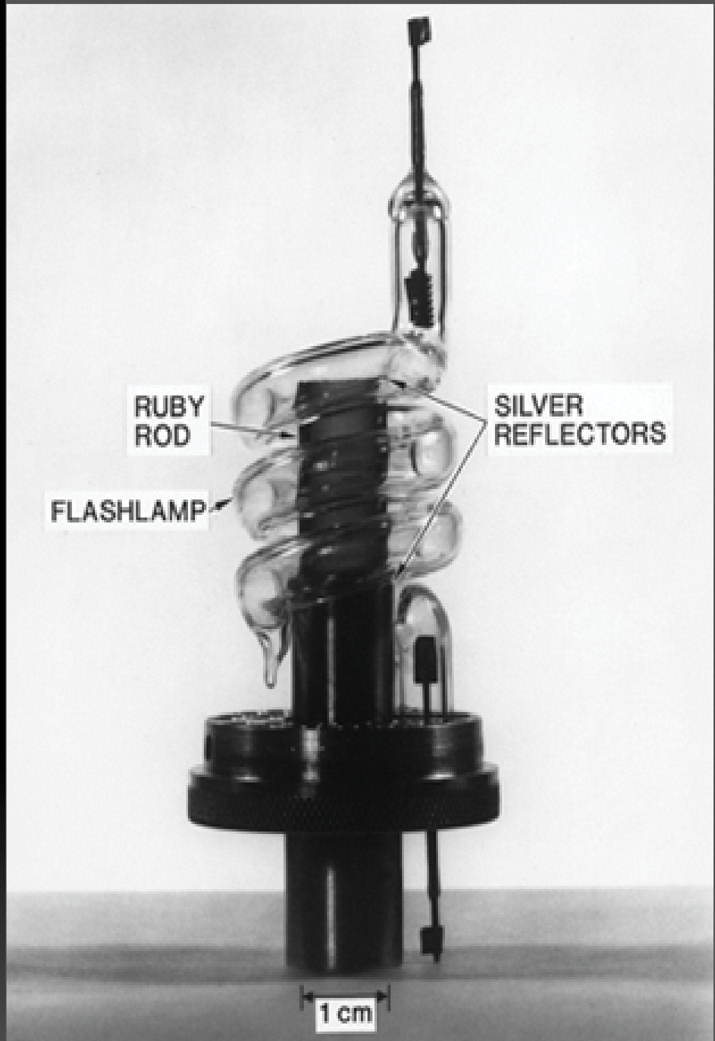
LASERS AND THE EYE

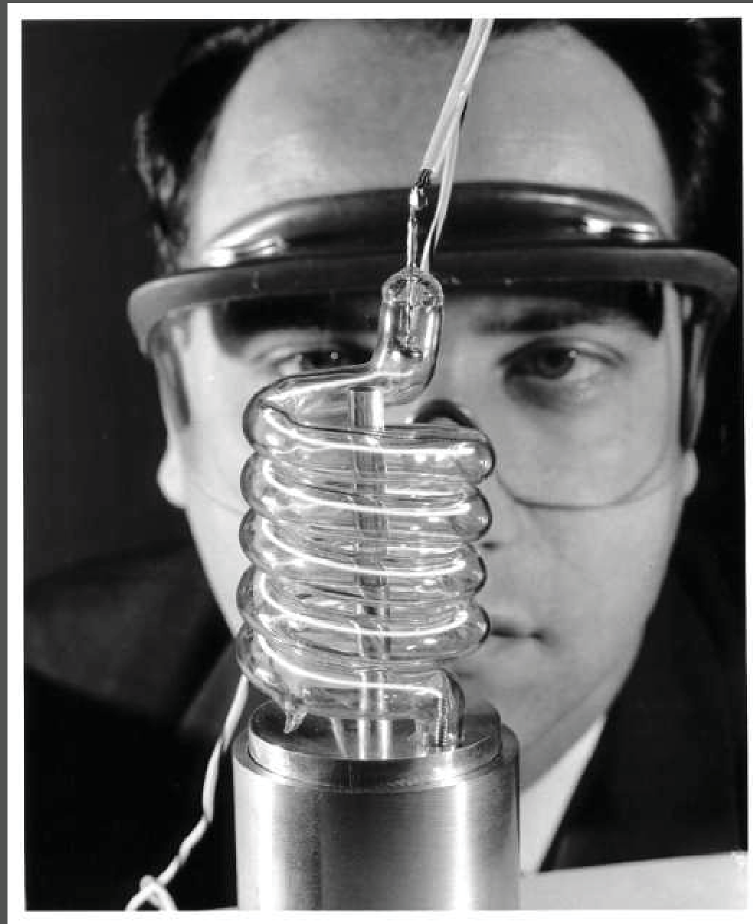


Charles Townes and Jim Gordon with the NH3 maser.



LASERS AND THE EYE

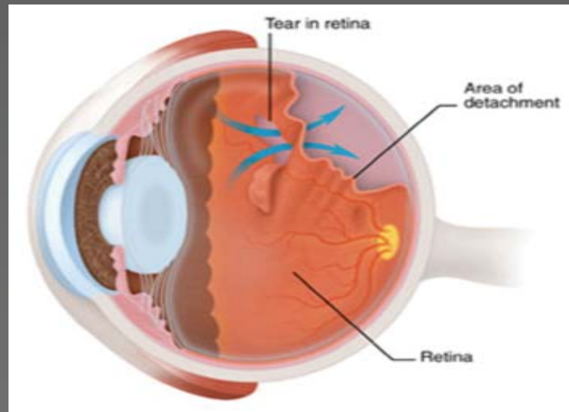


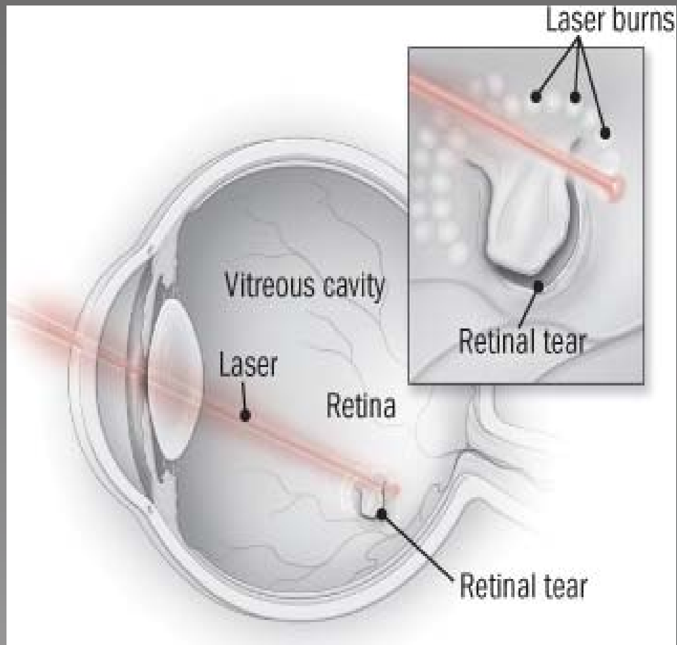


First Ruby Laser (actual size)
Theodore Maiman and Hughes Lab publicity Photo

Lasers and the Eye

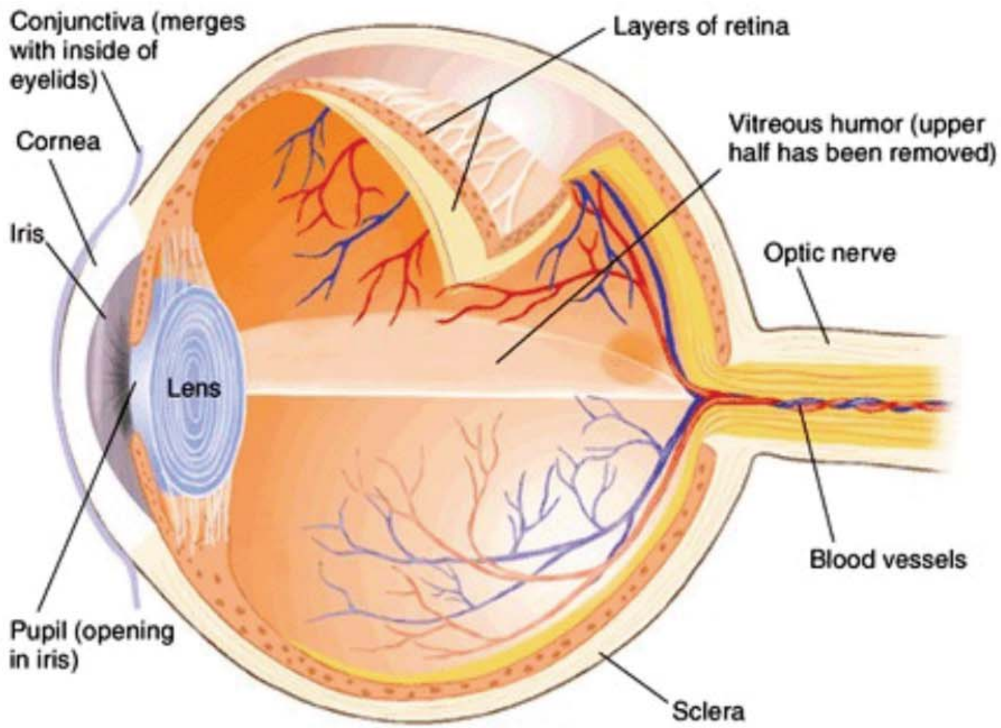
- First application came in 1961.
- Dr. Charles Campbell at Columbia University
- Procedure called photocoagulation
- Surgery on the retina



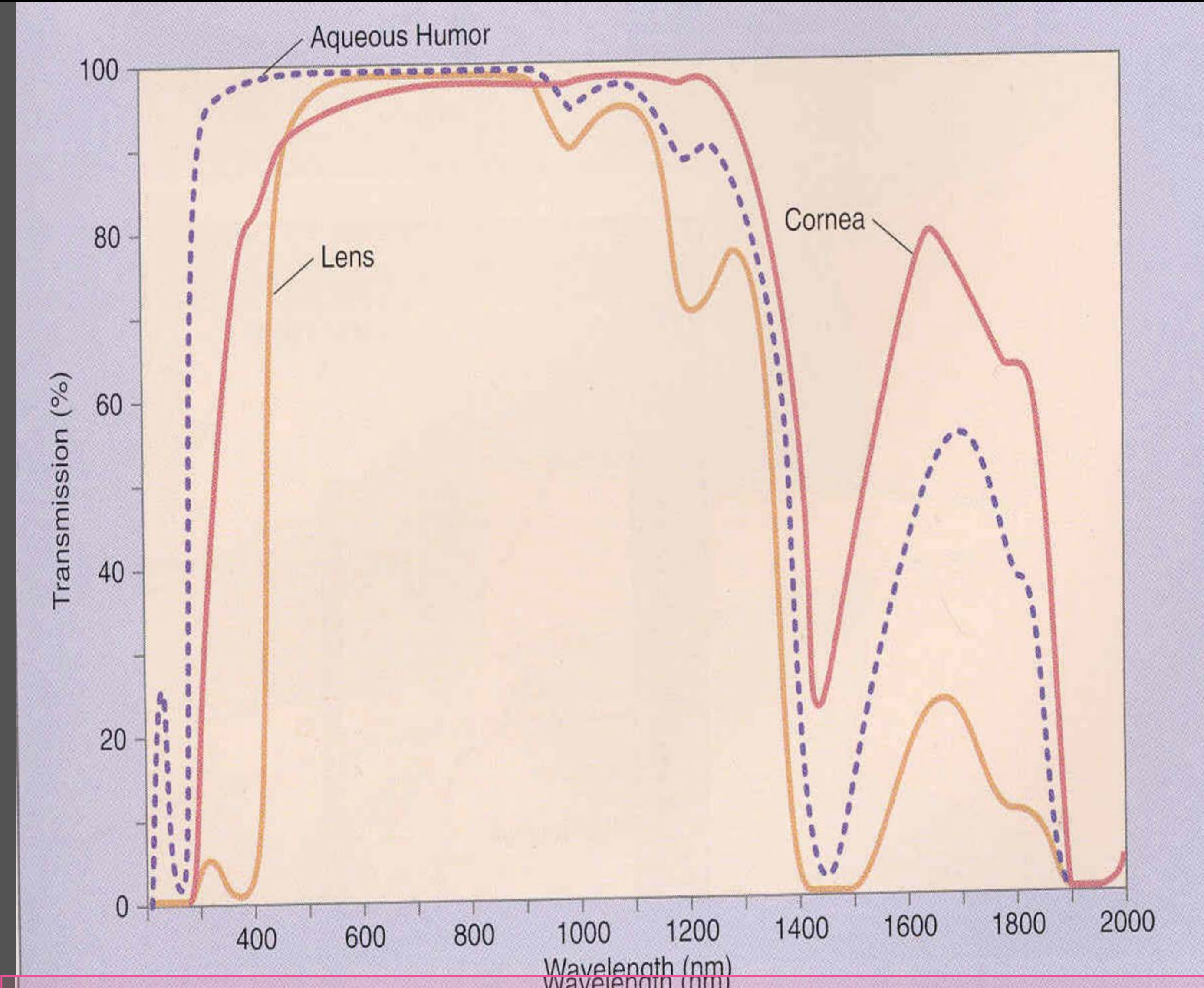


LASERS AND THE EYE

► **The Human Eye**

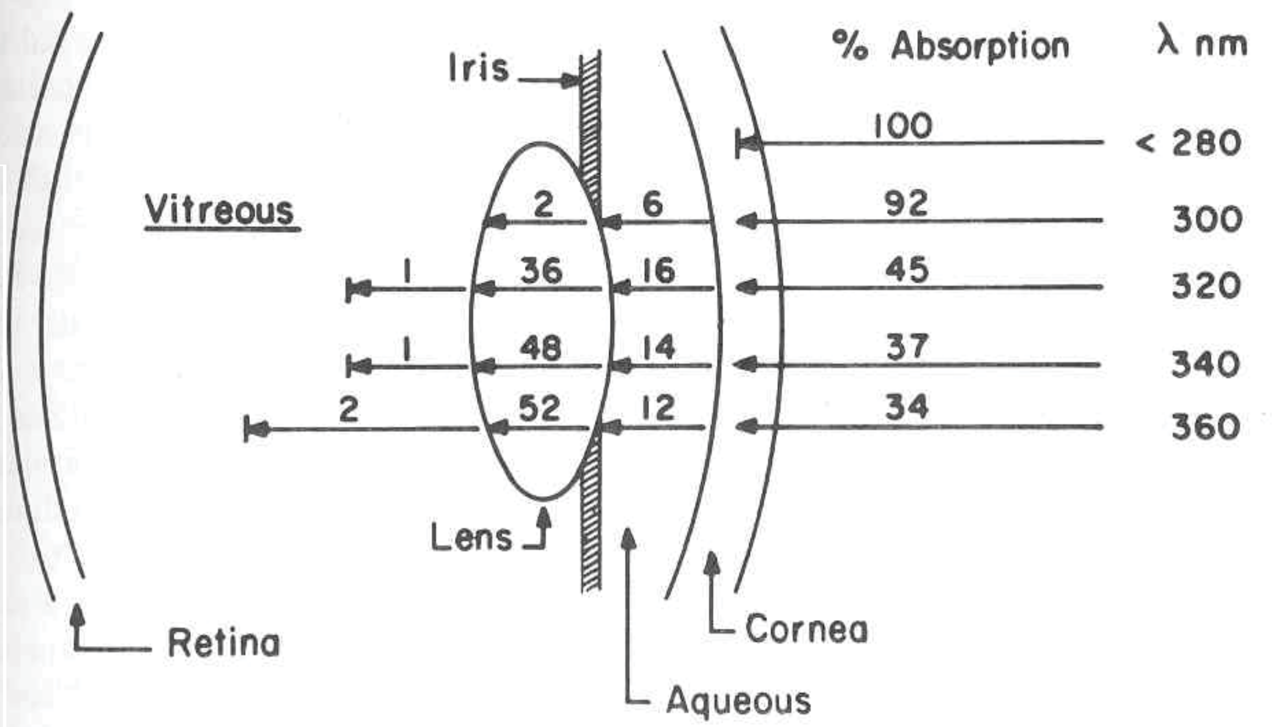


LASERS AND THE EYE



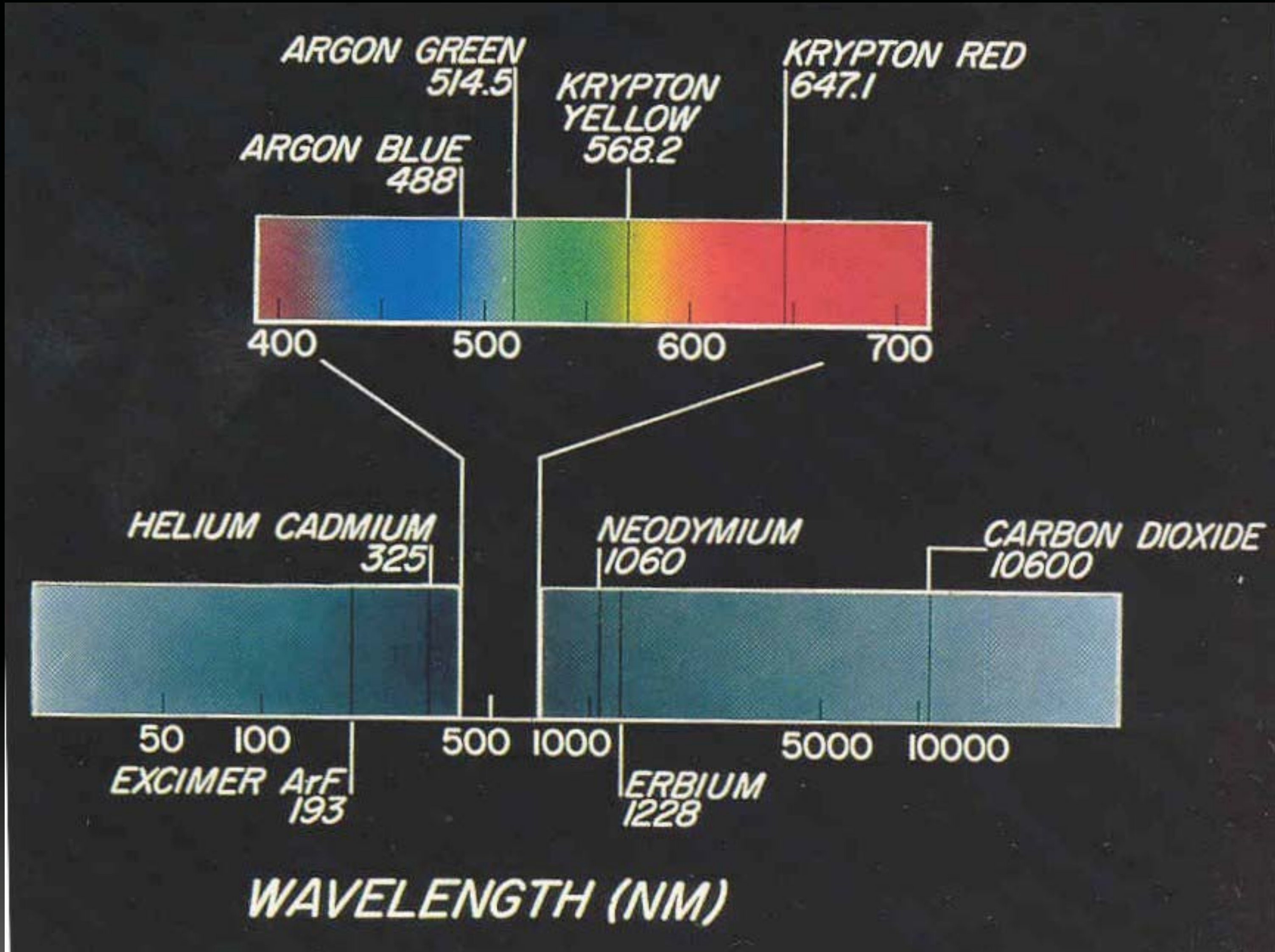
Absorption spectra for various ocular components

LASERS AND THE EYE

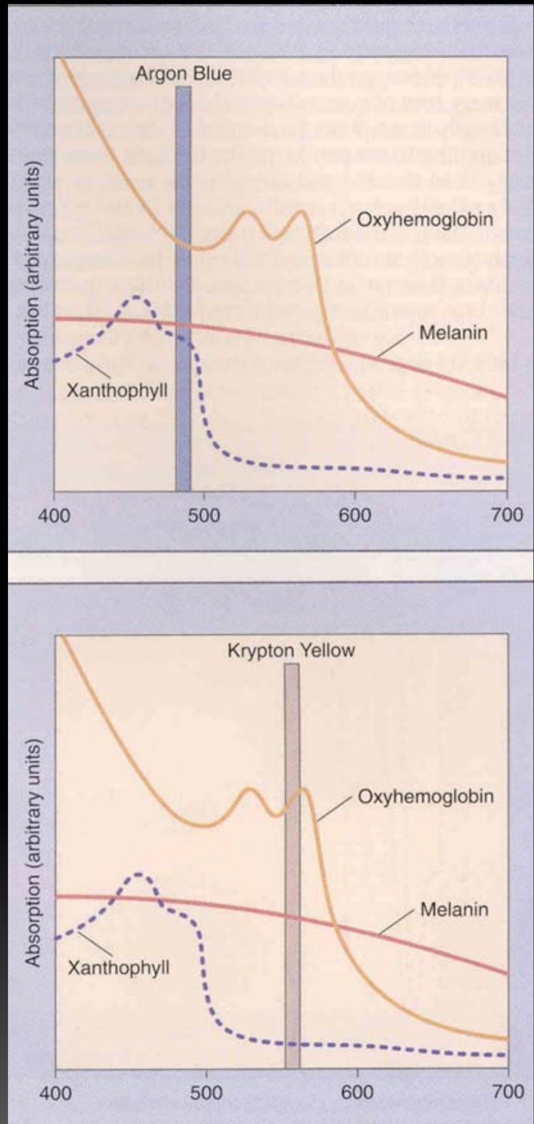


WAVELENGTH OUTPUT FOR LASERS

Laser type	λ (nm)	Laser type	λ (nm)
ArFl(excimer-uv)	193	Nd YAG(green)	532
KrCl(excimer – uv)	222	Krypton(yellow)	568
Krypton(blue)	476	He Neon(green)	543
Argon(blue)	488	Nd YAG (IR)	1064
Argon(green)	514	He Neon(IR)	1150
Krypton(green)	528	Erbium(IR)	1504
He Neon (yellow)	594	Hydrogen flouride(IR)	2700
Krypton(red)	647	CO_2(IR)	9600
Ruby (Red)	694		


ARGON GREEN 514.5
KRYPTON YELLOW 568.2
KRYPTON RED 647.1
ARGON BLUE 488
400
500
600
700
HELIUM CADMIUM 325
NEODYMIUM 1060
CARBON DIOXIDE 10600
50
100
500
1000
5000
10000
EXCIMER ArF 193
ERBIUM 1228
WAVELENGTH (NM)

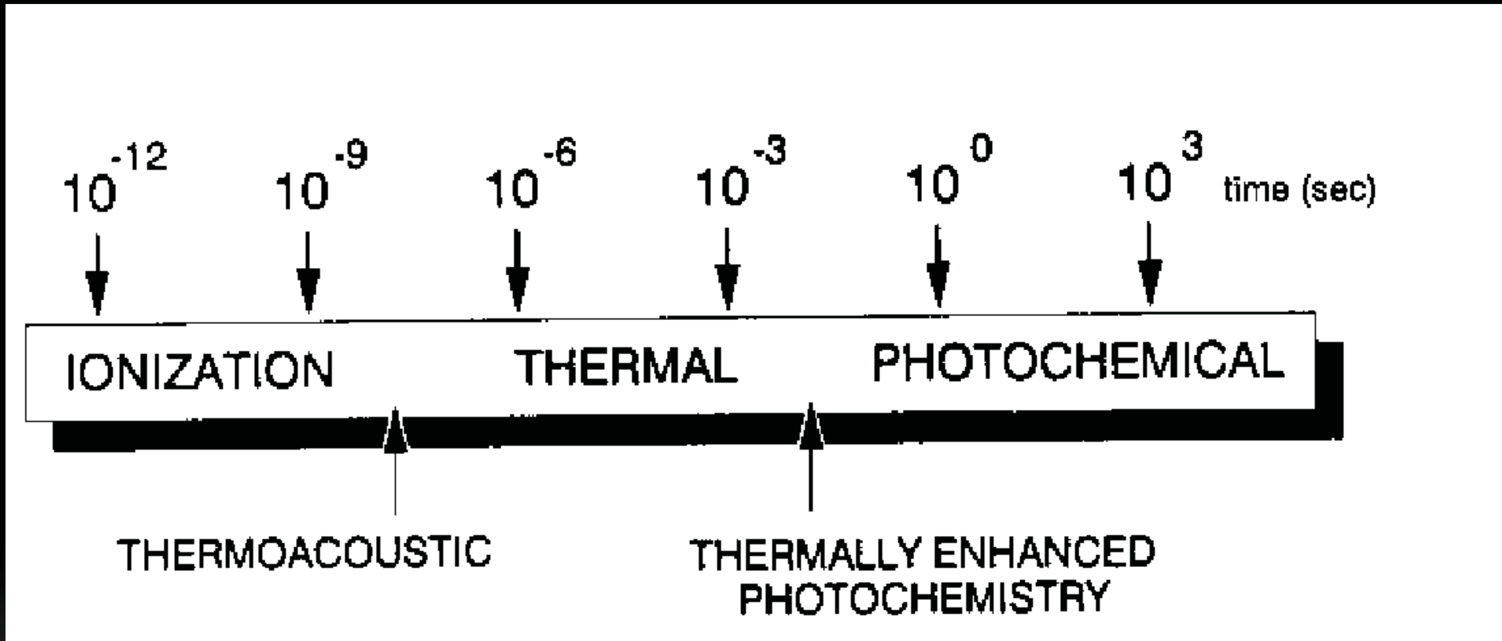
WHICH WAVELENGTH LASER TO USE?



LASER INTERACTION WITH BIOLOGICAL TISSUE

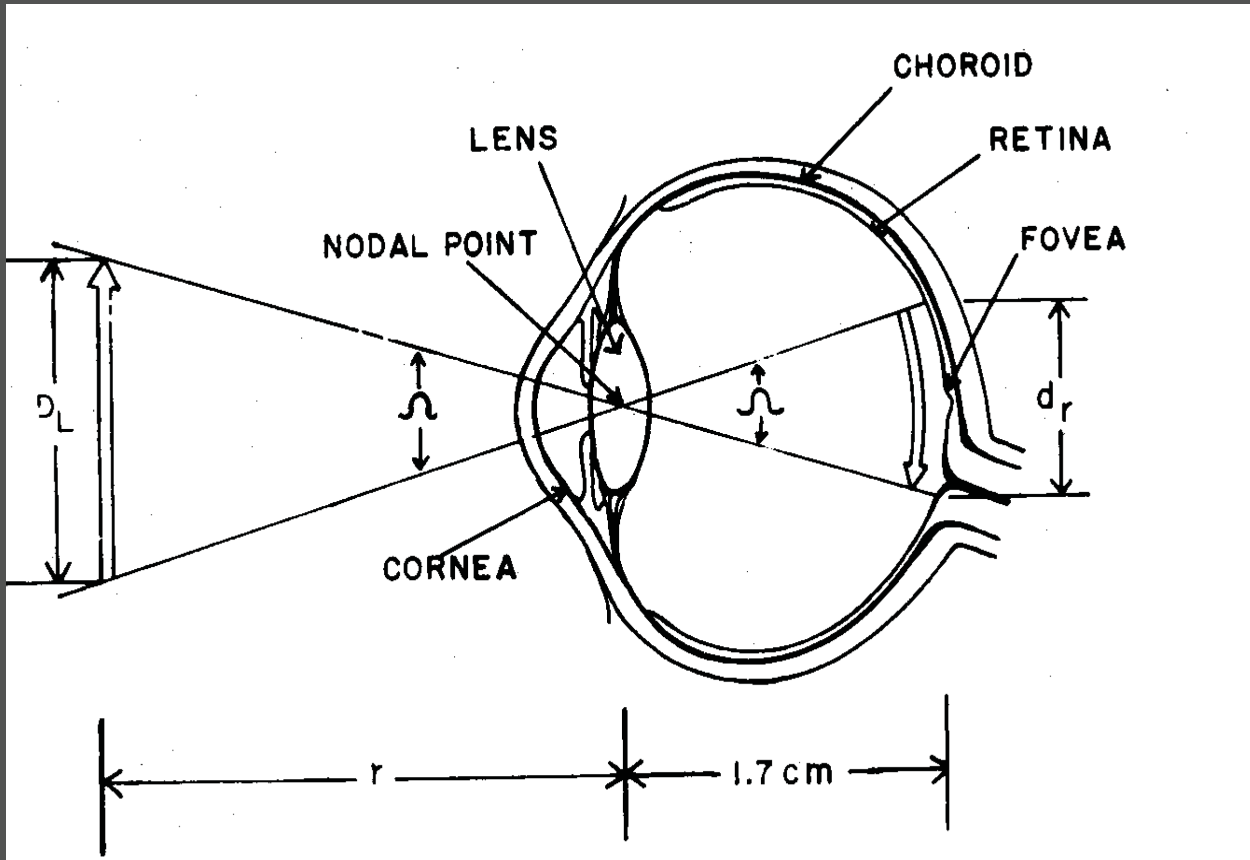
Photcoagulation : thermal effect (e.g.: Argon / Krypton lasers)
Photochemical effect (e.g.: Excimer lasers)
Photodisruption (e.g.: Nd:YAG lasers)
Photodynamic therapy
Photovaporization

LASERS AND THE EYE



Time of exposure also matters

RETINAL IRRADIANCE CALCULATIONS



RETINAL IRRADIANCE (EXPOSURE RATE)

E_r = [illegible] L_s [illegible] d_e / $4f^2$

L_S = Source radiance W cm^{-2}

f = effective focal length of eye (cm)

d_e = pupil diameter

[illegible] = transmittance of ocular media

Term	Symbol	Description	Defining equation	Units of measure
Radiant energy	Q_e	Energy	——	J
Radiant energy density	w_e	Energy per unit volume	$w_e = \frac{\Delta Q_e}{\Delta V}$	J/m^3
Radiant flux	Φ_e	Energy per unit time (power)	$\Phi_e = \frac{\Delta Q_e}{\Delta t}$	J/s or W
Radiant exitance	M_e	Power emitted per unit area of source	$M_e = \frac{\Delta \Phi_e}{\Delta A}$	W/m^2
Irradiance	E_e	Power falling on unit area of target	$E_e = \frac{\Delta \Phi_e}{\Delta A}$	W/m^2
Radiant intensity	I_e	Source power radiated per unit solid angle	$I_e = \frac{\Delta \Phi_e}{\Delta \omega}$	W/sr
Radiance	L_e	Source power radiated per unit area per unit solid angle	$L_e = \frac{\Delta \Phi_e}{\Delta \omega \Delta A} = \frac{I_e}{\Delta A}$	W/m^2-sr

Abbreviations: J, joule; W, watt; m, meter; s, second; sr, steradian.

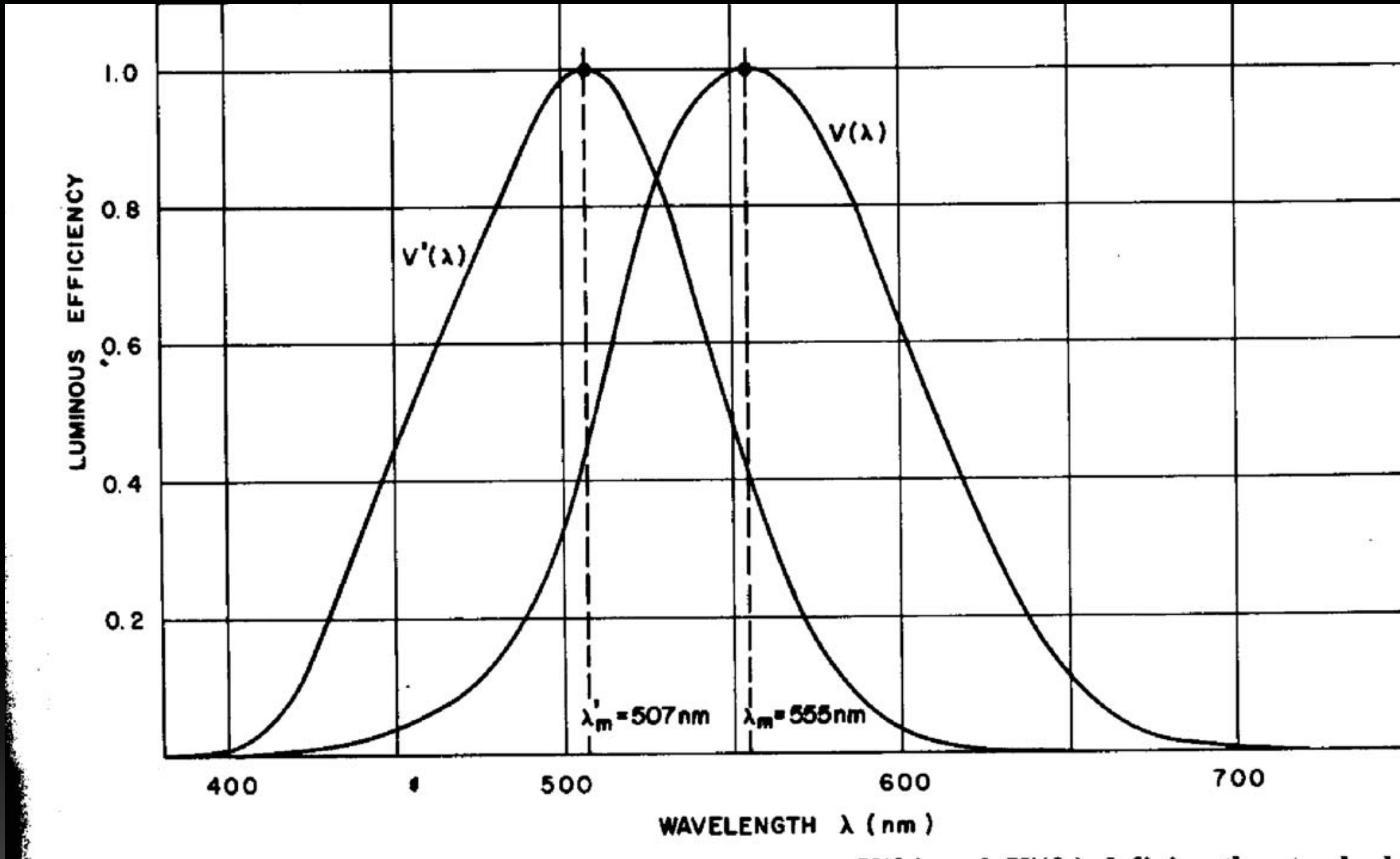
PHTOMETRIC UNITS

Term	Symbol	Description	Defining equation	Units of measure	Analogous radiometric term
Luminous energy	Q_v	Luminous energy in visible spectrum	——	talbot	joule
Luminous power	Φ_v	Luminous power per unit time (power)	$\Phi_v = \frac{\Delta Q_v}{\Delta t}$	lumen (talbot/s)	watt (joule/s)
Luminous exitance	M_v	Luminous power per unit area of source	$M_v = \frac{\Delta \Phi_v}{\Delta A}$	lumen/m^2 (lux)	watt/m^2
Illuminance	E_v	Luminous power per unit area of target	$E_v = \frac{\Delta \Phi_v}{\Delta A}$	lumen/m^2 (lux)	watt/m^2
Luminous intensity	I_v	Luminous power emitted per unit solid angle	$I_v = \frac{\Delta \Phi_v}{\Delta \omega}$	lumen/sr (cd)	watt/sr
Luminance	L_v	Luminous power per unit solid angle per unit area of source	$L_v = \frac{\Delta \Phi_v}{\Delta \omega \, \Delta A}$	lumen/m^2-sr	watt/m^2-sr

Abbreviations: sr, steradian; lm, lumen; lx, lux; cd, candela (candle); ft-cd, foot-candle.
Equivalences: lx = lm/m^2; cd = lm/sr; ft-cd = lm/ft^2 = 10.76 lm/m^2.

Radiometric and photometric units are related by the spectral sensitivity of the eye – the so called V-λ curve

SPECTRAL LUMINOUS EFFICIENCY CURVES



Both photopic and scotopic curves are shown

THE TROLAND

Retinal illuminance unit

Product of source luminance (cd m^{-2})
and pupil diameter squared $(mm)^2$

RETINAL IRRADIANCE

$E_r = L_s$ □ $d_e / 4f^2$

- L_S = Source radiance W cm^{-2}
- f = effective focal length of eye (cm)
- d_e = pupil diameter
- □ = transmittance of ocular media

ACCUMULATED RETINAL EXPOSURE

For lengthy exposures

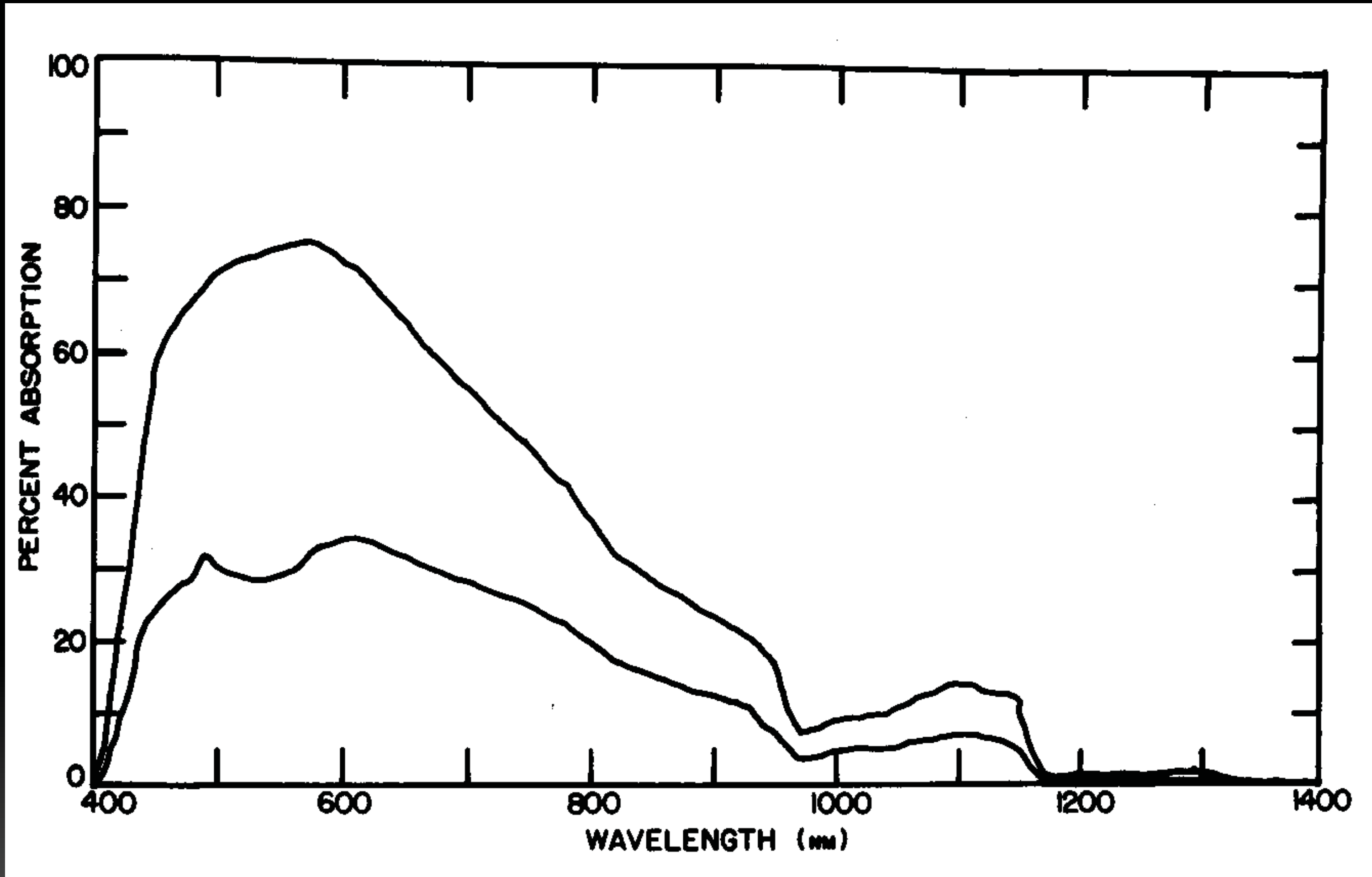
$$H = Et$$

Radiant exposure = (Irradiance) (time)
($J\ cm^{-2}$) ($W\ cm^{-2}$) (s)

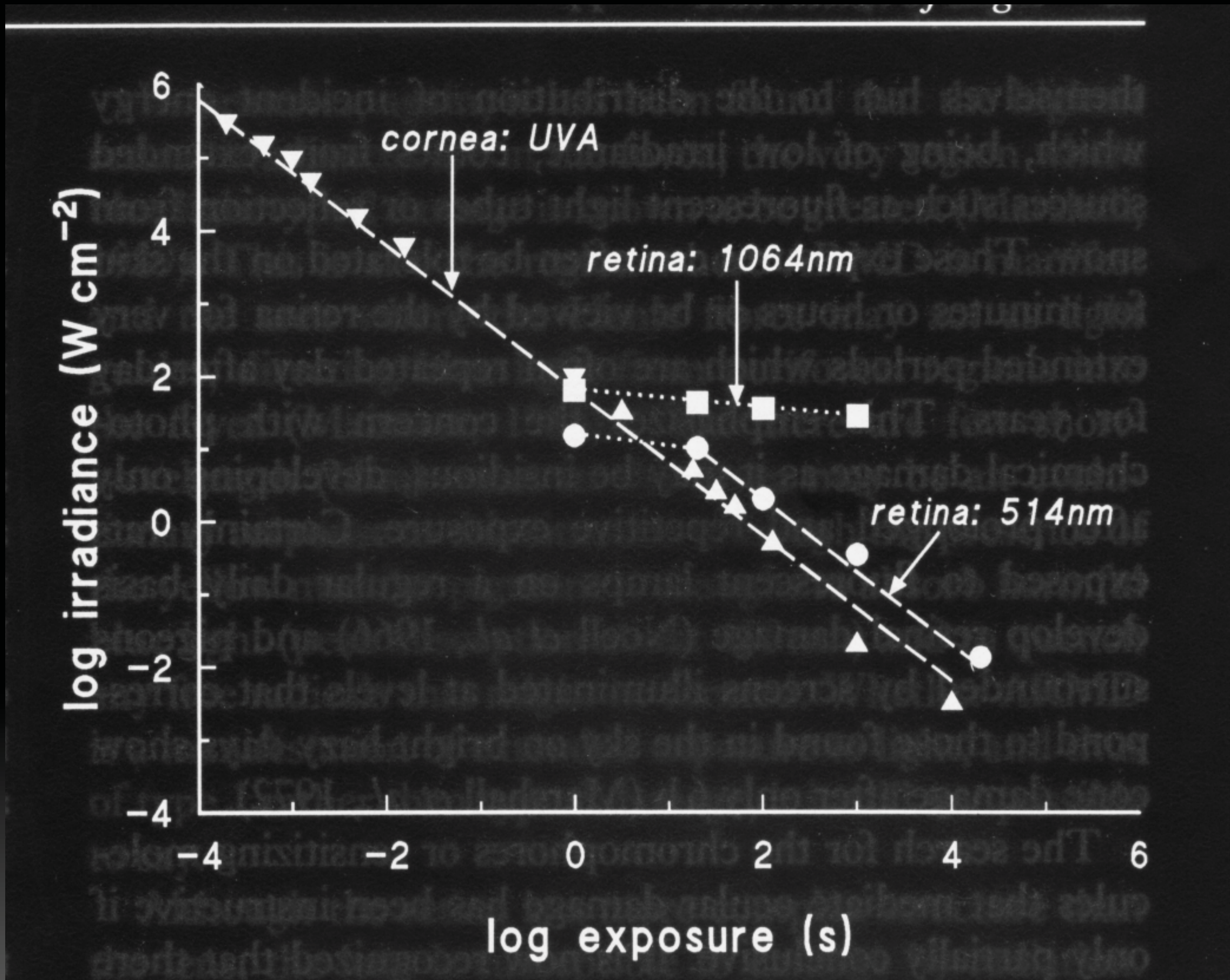
For Photochemical effects, we need to employ the action spectrum (i.e., .the V-Lambda curve)

Need to consider size of light source and impact of eye movements in any calculation of retinal exposure dose

RELATIVE SPECTRAL EFFECTIVENESS CURVE FOR RETINAL THERMAL INJURY

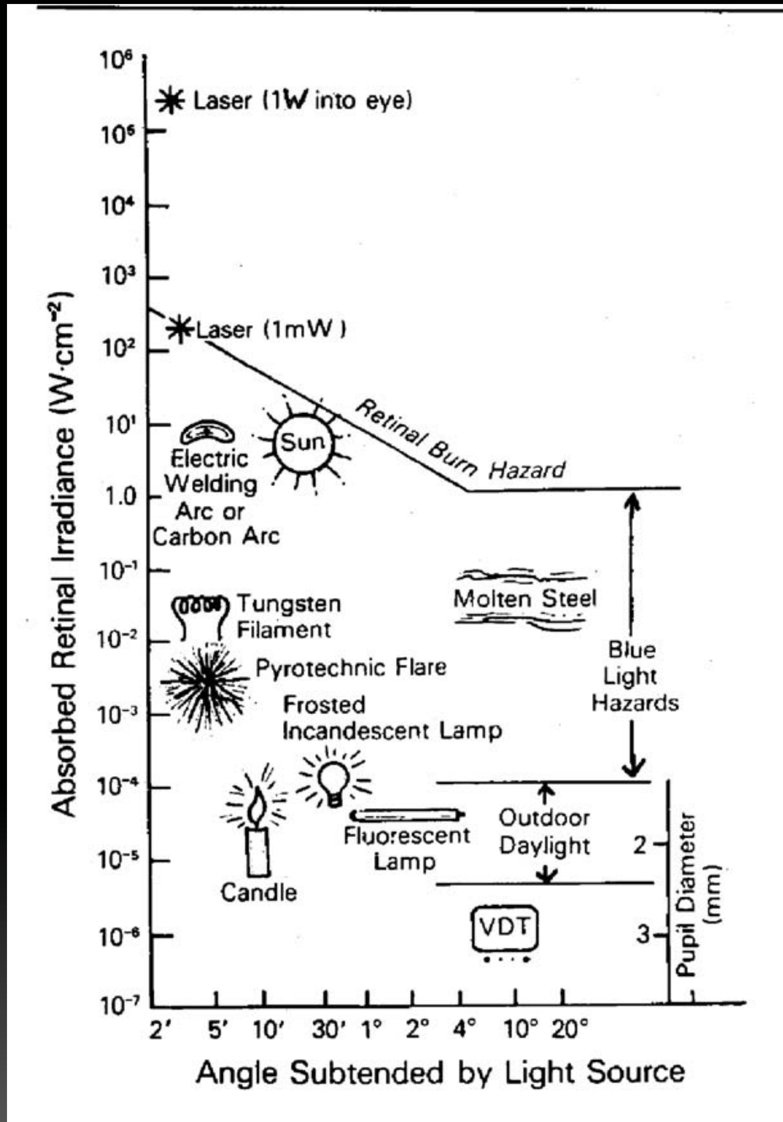


Top curve: retina and chorodial spectral absorption values corrected for fundus reflectance
Bottom curve: product of top curve and spectral transmissiojn fucntion of the ocular media



cornea: UVA
retina: 1064nm
retina: 514nm
log irradiance (W cm^{-2})
log exposure (s)

ABSORBED RETINAL IRRADIANCE DUE TO VARIOUS SOURCES



Photochemical damage

1. Photochemical damage can occur at long time exposures and low irradiances

2. Delay in development of observable reaction

3. Widely distributed and diffuse

- Type I
  - long exposure (hours or days)
  - Very low irradiances; large areas

  Action spectra of type I damage coresponds to absorption spectrum of uveal pigment

- Type II "blue light hazard"
  - higher irradiances
  - Shorter exposures
  - Size of areas smaller

- Mechanism of damage involves free radicals and probably singlet O_2

- Action spectrum of Type II damage peaks 425 nm

Thermal damage

- energy derived from direct absorption into vibrational states (incident IR) or from relaxations of electronically excited states (uv or visible) – internal conversion
- Thermal effects only occur when energy is widely distributed within target molecules
- Melanin and hemoglobin – major chromophores
- No heat lost by radiation
- Convection requires free circulation of heated fluid
- Amount of heat lost from volume of exposed chromophore depends on surface area to volume ratio

MODELS OF THERMAL DAMAGE

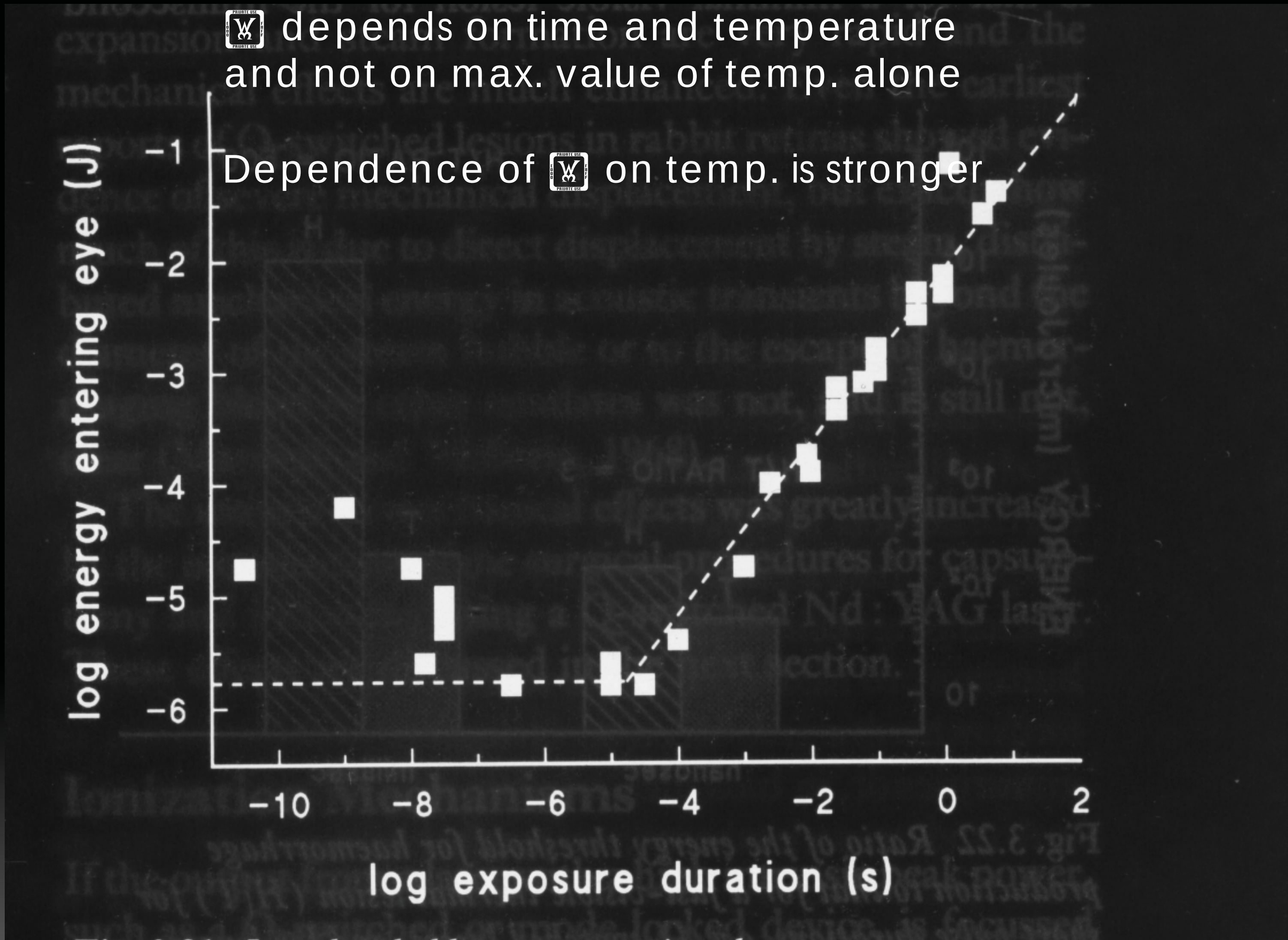
In general,

- $$\Omega = C_1 \int_{t_i}^{t_f} \exp\left(\frac{-C_2}{T(r,z)}\right) dt$$

Ω = fraction of molecules denatured for a temp T between initial time t, and final time t_f as a function of radial distance r from the center of retinal image along the z axes of laser beam

[illegible] depends on time and temperature
and not on max. value of temp. alone

Dependence of [illegible] on temp. is stronger

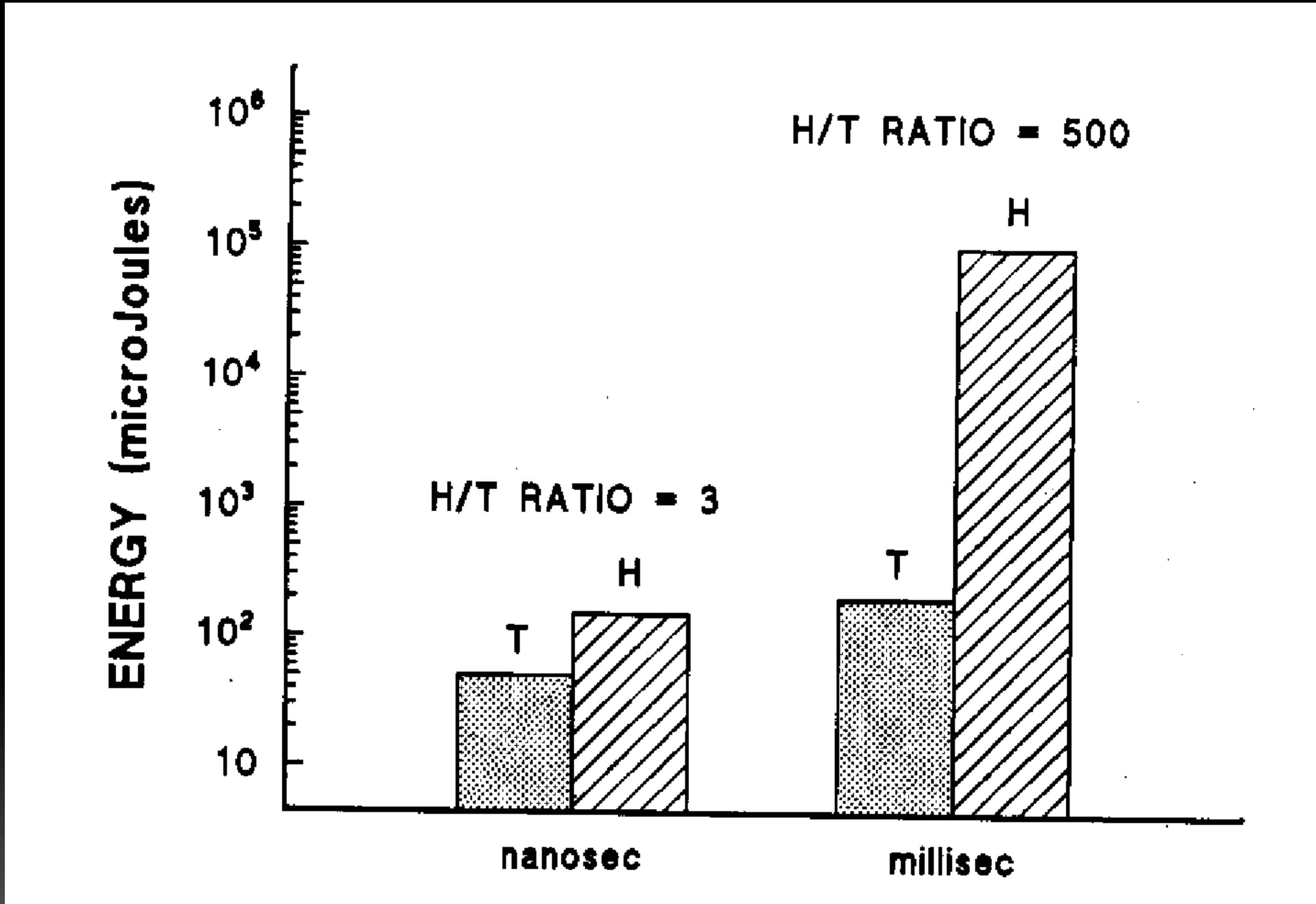


1. Relation between energy and duration

   □ □ t ¾

2. Below 20 □s □ flat since there is little or no time for heat to flow from image volume "thermal relaxation time"

3. As pulse length □ threshold actually increases



Very short exposures ---hemorrhage

Thermal damage

- energy derived from direct absorption into vibrational states (incident IR) or from relaxations of electronically excited states (uv or visible) – internal conversion
- Thermal effects only occur when energy is widely distributed within target molecules
- Melanin and hemoglobin – major chromophores
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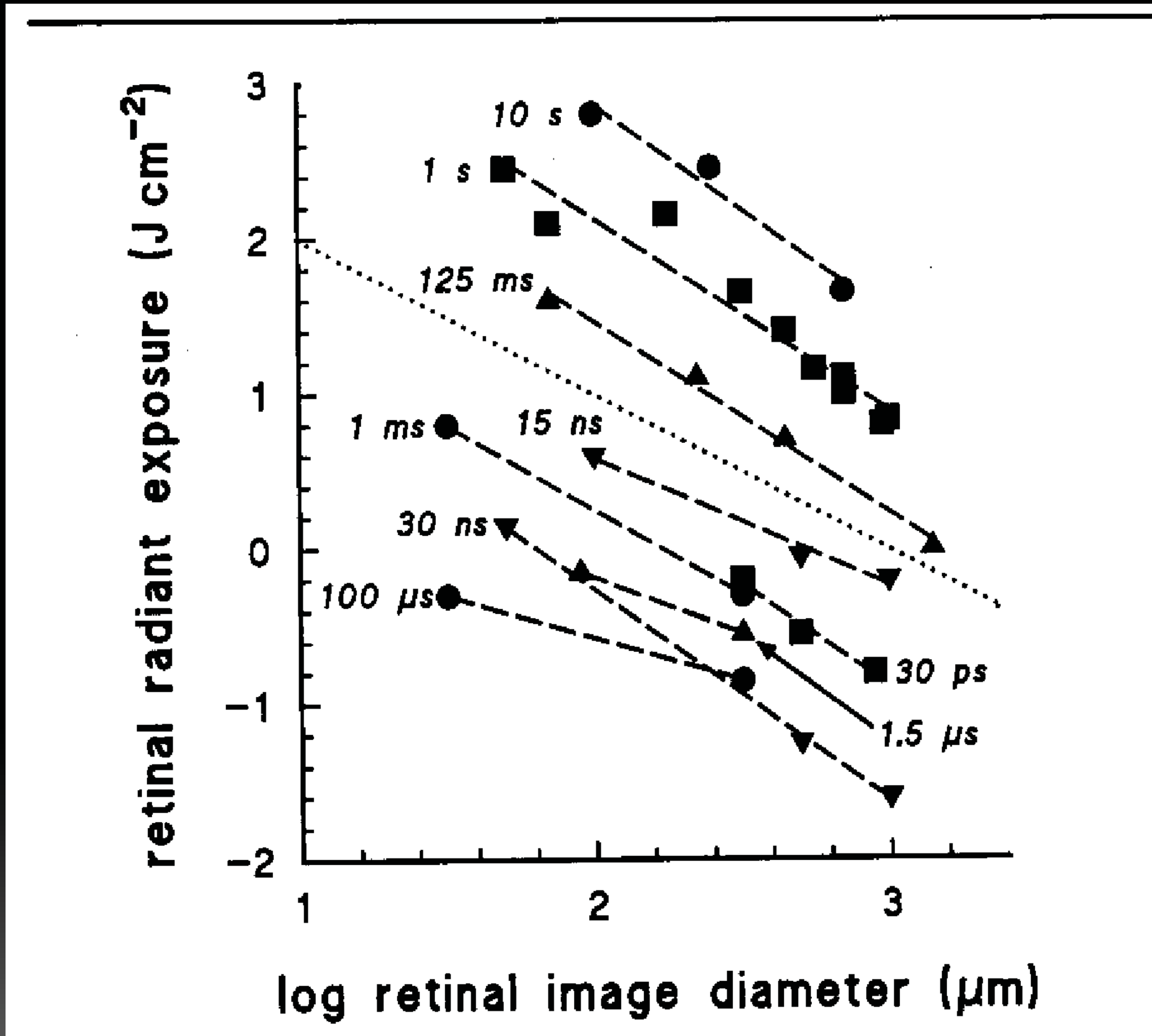
RELATIONSHIP BETWEEN THRESHOLD RADIANT EXPOSURE AND IMAGE DIAMETER



Other mechanisms: thermo acuoustic and ionization

BASIC BIOLOGICAL EFFECTS OF LASER LIGHT ON EYE AND SKIN

	Eye effects	Skin effects
UVC(200-280nm)	photokeratitis	Erythema(sunburn) Skin cancer
UV B (280-315nm)	photokeratitis	Accelerated skin aging
UVA (315-400nm)	Photochemical uv cataract	Pigment darkening and skin burn
Visible (400-700)	Photochemical and thermal injury	Photosensitive reactions, skin burn
IR A (780-1400nm)	Cataract, retinal burns	Skin burn
IR B (1400-3000nm)	Corneal burn, aqueous flare, IR cataract	Skin burn
IR C 3000nm-1000µm	Corneal burn only	Skin burn

LASER HAZARD CLASSES

Class I : emit radiation at low radiation hazard levels. Continuous wave(cw) 0.4 mW at visible wavelengths

Class I A: 1000second exposure, not intended for viewing. Power limit – 4.0MW. Eg. Supermarket scanner

Class II : low power visible lasers but emit above class I (not above 1mW)

Class IIIA: intermediate power lasers (cw: 1.5mW). Hazardous for intra beam viewing

Class IIIB: moderate power lasers (cw 5-500mW, pulsed: 10 J/ cm^2). Produce hazardous diffuse reflection.

Class IV: High power lasers (cw: 500mW, pulsed 10 J/ cm^2). Hazardous to direct or diffusely scattered laser beam.

LASER CLASSIFICATION

Class	UV	VIS	IR	Direct ocular	Diffuse ocular
I	X	X	X	no	no
IA		X		Only after 1000sec	no
II		X		Only after 0.25sec	no
IIIA	X	X	X	yes	no
IIIB	X	X	X	yes	Only when laser output is near class IIIB limit of 0.5 watt
IV	X	X	X	yes	yes

Key: X indicates class applies in wavelength range

LASER EXPSOURE LIMITS MPE

Laser Exposure Limits – Maximum permissible exposure limits (MPE) (developed by ANSI Z 136.1 “safe use of laser standards” 1993)

- **0.25 seconds**: human aversion time for bright light(blink reflex)
- **10 seconds:** represent optimum “worst case” time period for ocular exposure to IR (natural eye motions dominate period longer than 10sec)
- **600 seconds**: worst case period for viewing visible diffuse reflections during tasks like alignment
- **30,000 seconds:** 8 hour occupational exposure (1 full day).

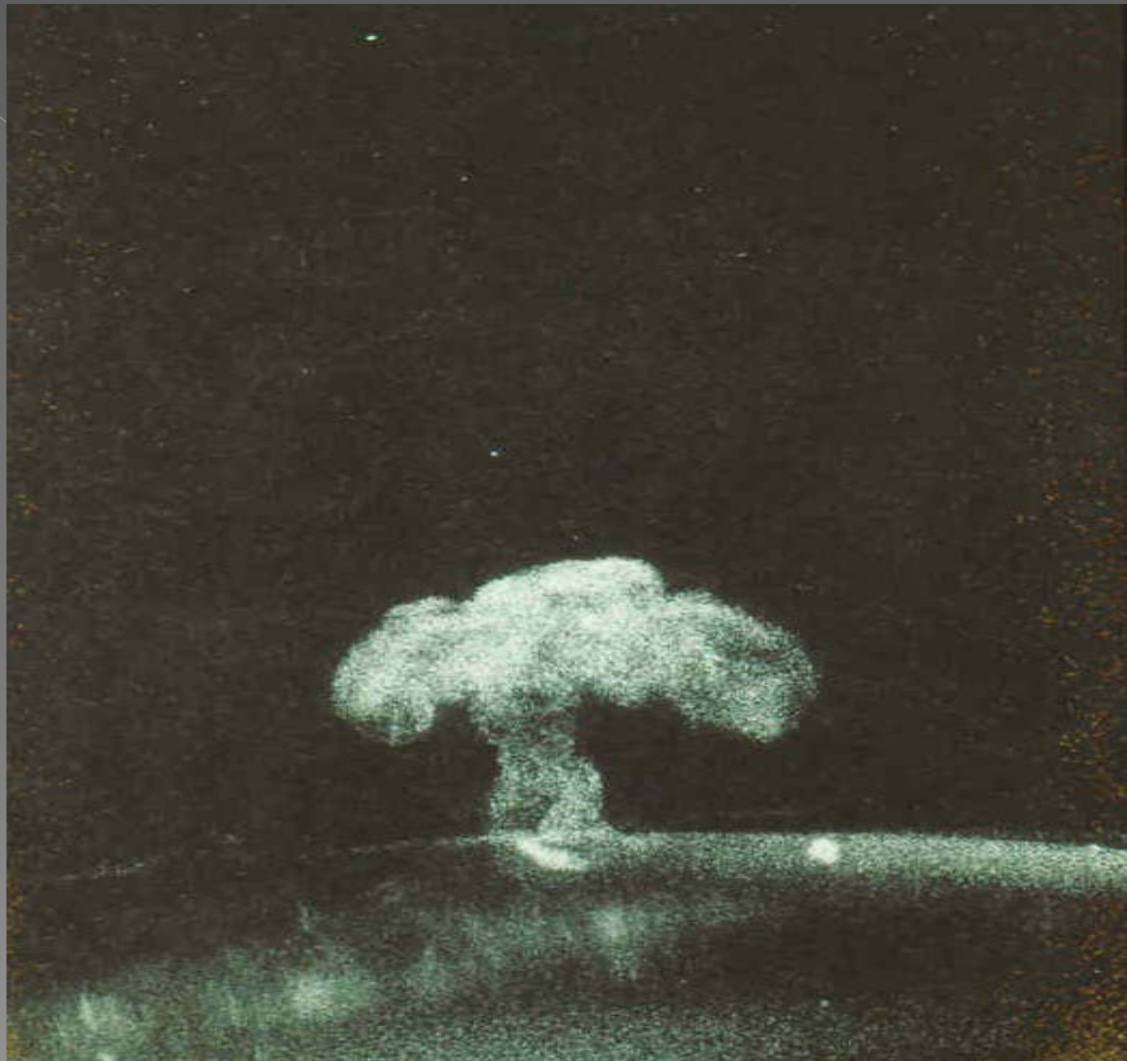
LASER EXPOSURE LIMITS

Laser type	λ (nm)	0.25sec	10sec	600sec	30,00sec
CO_2(CW)	1060	---	100 x 10^{-3}	---	100 x 10^{-3}
ND: YAG (CW)	1330	---	5.1x 10^{-3}	---	1.6 x 10^{-3}
Nd: YAG (Q-switched)	1064	---	17.0x 10^{-6}	---	610x 10^{-6}
He Ne (CW)	633	2.5 x 10^{-3}	---	293 x 10^{-6}	28.5 x 10^{-6}

MPE levels are in Watts/cm2

LASER EXPOSURE LIMITS (CONT.)

Krypton (CW)	647 568 530	2.5x 10^{-3} 31x 10^{-6} 16.7x 10^{-3}	--- --- ---	364x 10^{-6} 2.5x 10^{-3} 2.5x 10^{-3}	28.5x 10^{-6} 18.6x 10^{-6} 1x 10^{-6}
Argon (cw)	514	2.5x 10^{-3}	---	16.7x 10^{-6}	1x 10^{-6}
XeFl(excimer/cw)	351	----	---	---	33.3x 10^{-6}
XeCl(excimer/cw)	308	----	---	---	1.3x 10^{-6}



Types of laser safety eyewear available

Goggles:

- fit tightly on the face
- typically worn over vision-correcting prescription eye glasses
- usually constructed with frame vents to minimize lens fogging
  larger, heavier than spectacles or wraps

Spectacles

A frame that usually has two separate lenses with side shields

Can be made with vision-correcting prescription eye glasses

Wraps

- A frame with a single lens that covers both eyes

- Usually lighter than spectacles/goggles

What are the technical considerations for eye safety?

1. *Maximum permissible exposure (MPE)*, is the level of laser radiation to which a person may be exposed without hazardous effects or biological changes in the eye. MPE levels are determined as a function of laser wavelength, exposure time and pulse repetition. The MPE is usually expressed either in terms of radiant exposure in J/cm^2 or as irradiance in W/cm2 for a given wavelength and exposure duration.

- Exposure to laser energy above the MPE can result in tissue damage.
- The ANSI 136.1 standard defines MPE levels for specific laser wavelengths and exposure durations. Generally, the longer the wavelength, the higher the MPE; the longer the exposure time, the lower the MPE

What are the technical considerations for eye safety?

2. The Nominal Hazard Zone (NHZ) is the physical space in which direct, reflected or scattered laser radiation exceeds the MPE. LSE must be worn within the NHZ.

-In practical terms, when using dermatologic lasers the entire laser procedure room should be considered to be within the NHZ because the laser fiber or handpiece can be directed anywhere in the room.

Practical Pearls in Laser Eye Safety

1.Laser warning signs must be placed at the entrance to laser operating rooms.

2.Access to the laser operating room should only be granted to those individuals who have been appropriately ***educated in laser safety***. Each laser facility must develop its own Safety Procedures to be enforced by an appropriately trained ***Laser Safety Officer*** for the facility. Safety procedures should be in accordance with ANSI and OSHA guidelines (and others, where appropriate).

3.As LSE often looks alike in style and color, it is mandatory to ***check the wavelength and optical density*** imprinted on each pair of LSE prior to its use.

4.Color coding of the laser handpiece and LSE may help to minimize confusion especially in facilities where multiple laser wavelengths are available.

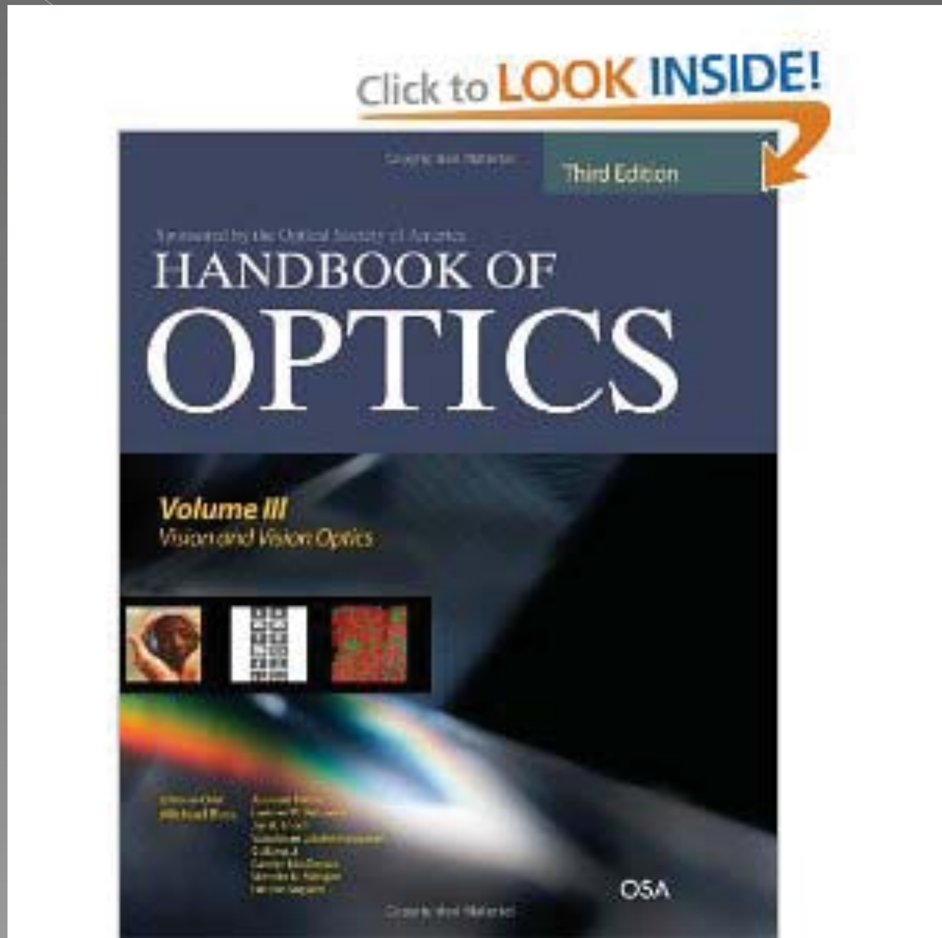
5. LSE should not move between laser rooms, nor should they be carried in lab coat pockets between use.

LSE can be very expensive, so proper care and handling is mandatory. The integrity of the LSE must be ***inspected regularly*** since small cracks or loose fitting filters may permit the laser beam to reach the eye directly.

The ***patient's eyes must always be protected*** from laser energy. If the patient is awake, appropriate opaque "mini" goggles must be worn. Great care must be taken to avoid accidentally exposing the straps of the patient goggles to laser light, since this can ignite them.

Whenever laser energy is used in the immediate vicinity of the eye (e.g. treating eyelids) ***a stainless steel or lead eye shield*** should be positioned on the surface of the orbit after the application of a topical ophthalmic local anesthetic. Plastic patient eye shields cannot be expected to withstand the thermal and mechanical effects of pulsed lasers, and should never be used.

A very good reference on laser interaction with the eye



THANK YOU!

Gordon
SCOTT
LE RAYON INFERNAL
DELPHY MAUREEN · TED CARTER · ALBERT DALBES · SILVIA SOLAR
MAX DEAN · TOR ALTMAYER
EASTMANCOLOR
WIDE SCREEN