

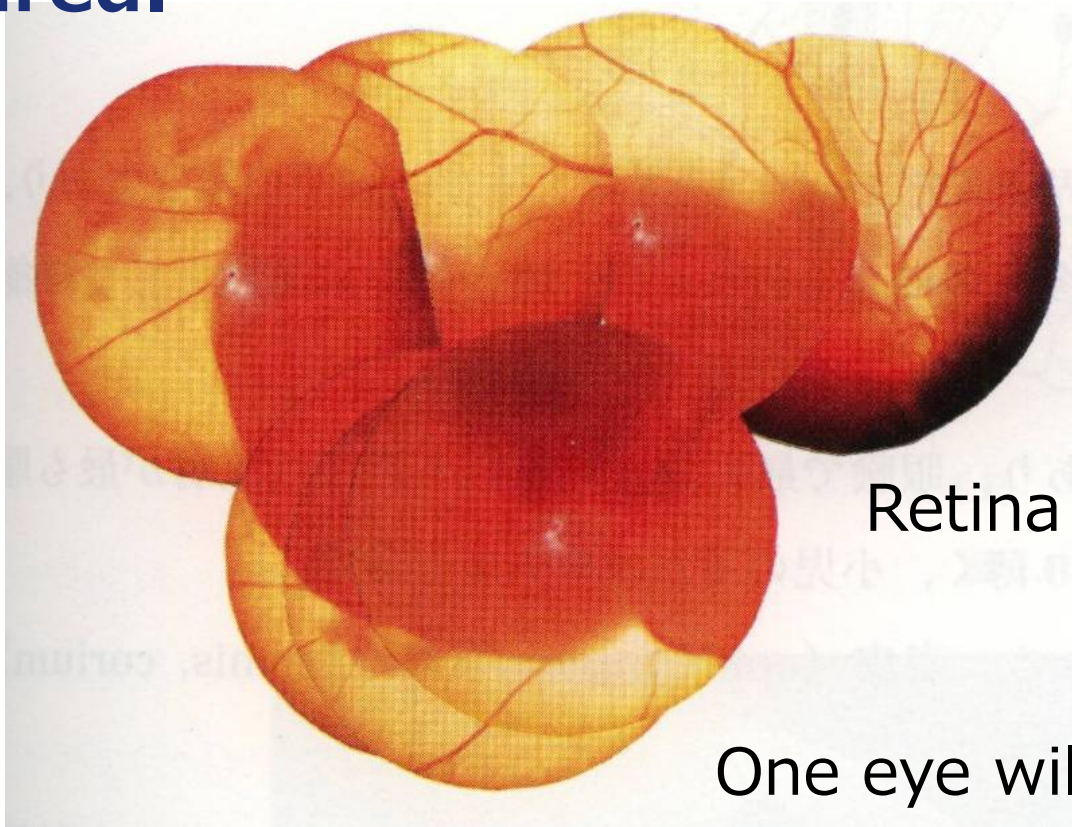
Dangers and safe use of lasers

(Laser Safety Training April 2025 Edition)

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Laser-induced visual impairment cannot be cured.



Retina damaged by laser

One eye will cease to function !

From 「Laser Safety Guidebook (New Technology Communication) 」

Most important

No one has ever gone blind wearing the correct laser goggles.

- The person who suffers the most from an accident is you.
- To protect yourself, understand the principles and follow them faithfully.
 - Experiments proceed outside the manual.
 - You can't prevent accidents if you can't judge the dangers for yourself and take measures to prevent them.

Structure of this course

Part 1 (Basic knowledge for laser users)

Part 2 (For those who assemble laser experimental systems)

- The instructor is not a laser safety expert.
- Only certain lasers are used in the laboratory.
 - There are many uses for lasers.
In my own lab, optical experiments on condensed matter systems are the main focus.

A few questions

- Do you know the type and wavelength of the laser you are using?
- Do you know the class of laser you are using?

Please raise your hand if you know both of them.

Types of laser accidents

- Building/Structure

- Fire (laser light and power supply system)
- Coolant leak

Do not stop laser light with combustible materials.

- Dark curtains without flameproof measures are dangerous.
- More than several hundred mW may cause ignition.

Be careful of water leakage if cooling water is used.

- Last person to leave should check for stoppages.
- Do not place table taps on the floor.

- Human body

- Electric shock
- Skin (burns)
- Eye (vision loss/blindness)

Electric shock

- Be careful of leakage current with 200V lasers.
- Be careful of high-voltage parts when the cover is open.

Burns, etc.

- Always check the path of light.
- For ultraviolet light sources (and non-lasers), do not expose the skin directly to the light.

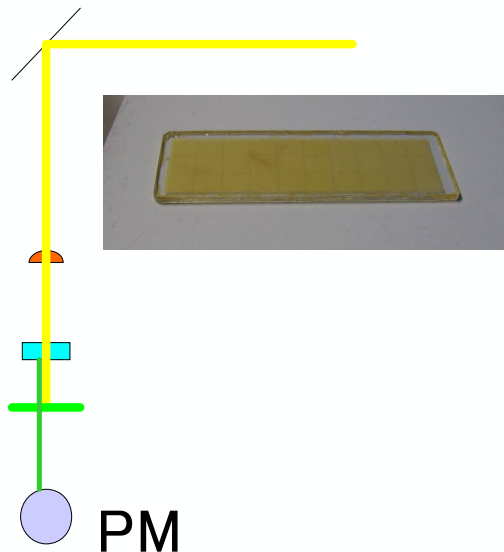
Laughable and Unlaughable Accidents

If there is no significant damage to the equipment and no disabling injuries (and no potential for disability), it can be funny afterwards.

Accidents that leave disability (blindness, loss of vision) cannot be laughed about later on
→ Only eye accidents must be prevented.

Examples of accidents

During adjustment of pulsed YAG-SHG optics



SHG material was sandwiched between glass slides to adjust the optical path, relying on the SH light. → Basic light reflected from the glass slide enters the eye

Cause:

Insufficient experience (education and training) and not wearing laser goggles (goggles were removed during adjustment because SH light was difficult to see)

The result was no disability, but this is no laughing matter !

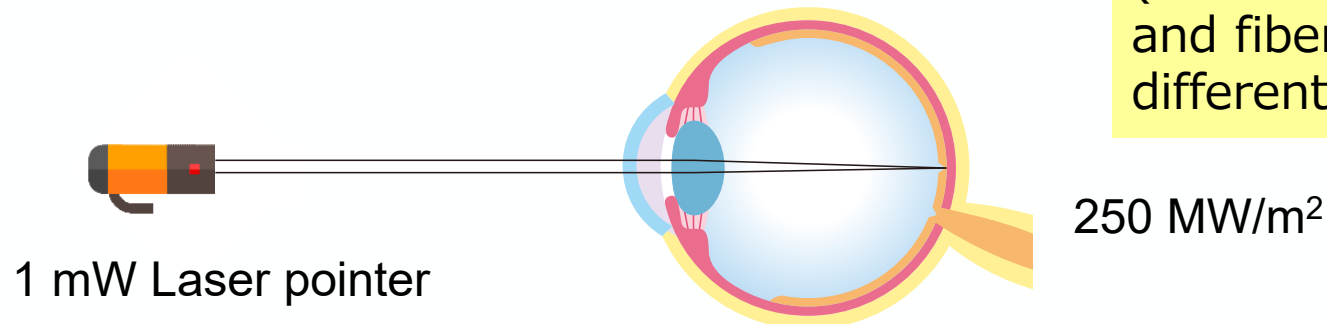
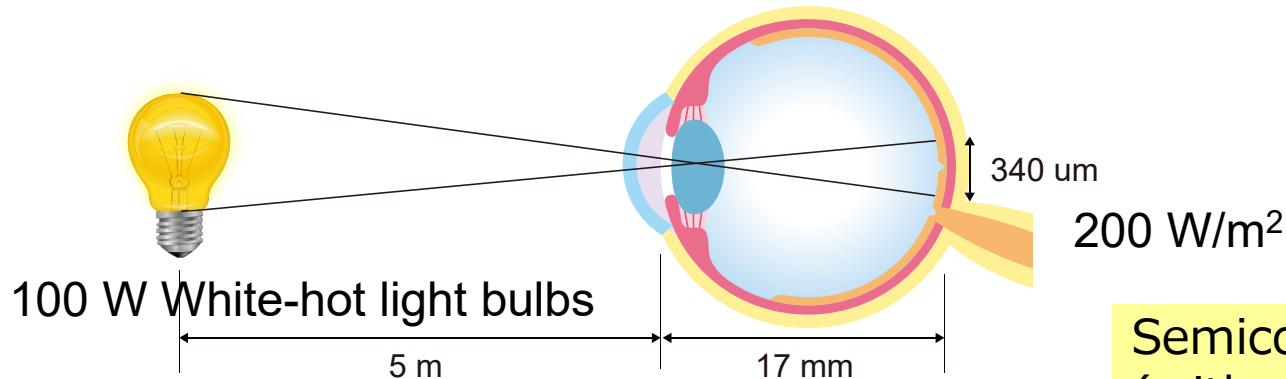
Both beginners and veterans get into accidents.

- Beginners
 - Because they don't know what not to do.
 - Carelessness
- Veteran
 - Carelessness due to familiarity
 - Unsubstantiated ideas about safety
 - Carelessness

Some people have come to visit and suffered eye damage.

Why are lasers dangerous?

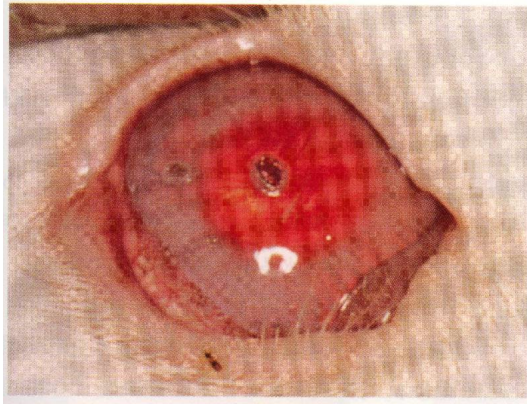
- High Intensity
 - Localized energy concentration (causes eye and skin damage, fire)
- Parallelism
 - Beam does not spread even at a distance (dangerous even at a distance)
 - Focuses on the retina in the unconscious state (dangerous if suddenly placed in the eye)



Semiconductor lasers (without collimating lens) and fiber are slightly different.

Which part of the eye is affected?

Damage to the cornea

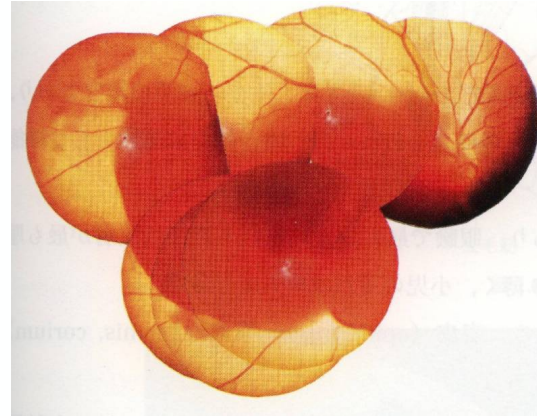


Laser-damaged rabbit eye

Ultraviolet and infrared lasers are absorbed by the cornea and damage the cornea.

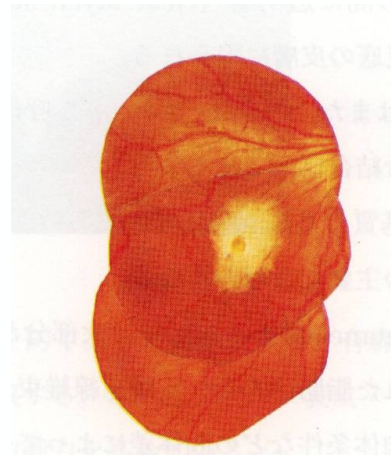
※ If the cornea's outer layer is damaged, it will recover, but if the inner layer is damaged, it will not.

Damage to the retina



Fundus hemorrhage caused by YAG laser (Immediately after the accident)

Hemorrhage over a large area

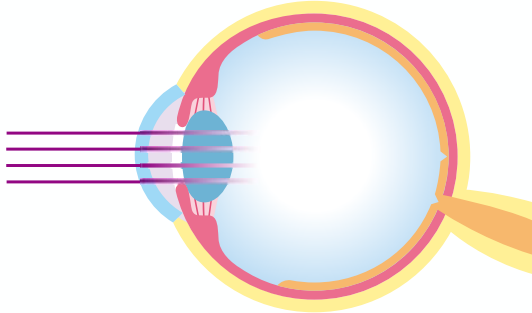
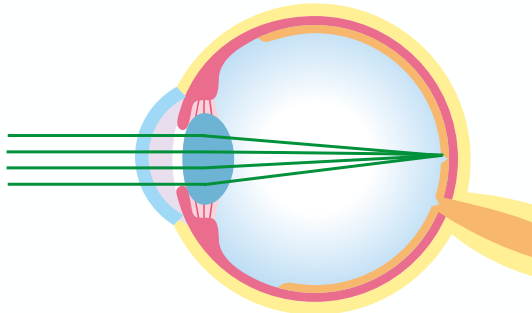
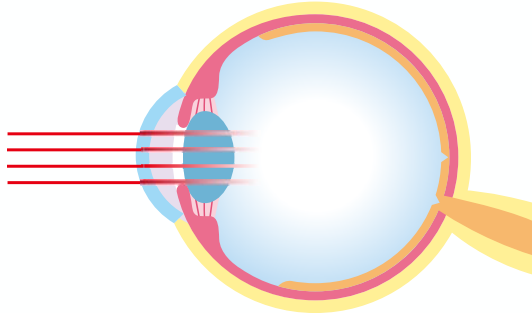


6 weeks later

Bleeding has subsided, but areas of retinal destruction appear.

→ Loss of vision or blindness.
The retina has no regenerative power and does not recover.

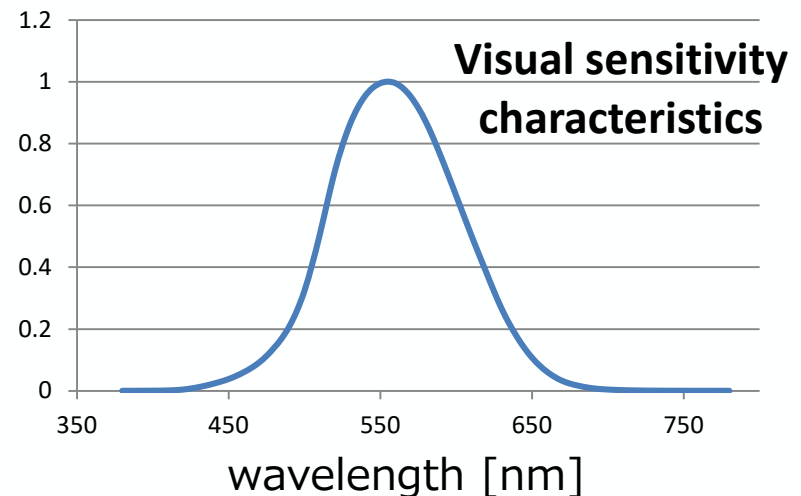
Where are the eyes and skin affected?

CIE wavelength region	Effect on eyes		Effect on skin
Ultraviolet C (180nm~280nm)		Photochemical keratitis	Erythema (sunburn) Accelerated skin aging process
Ultraviolet B (280nm~315nm)		Photochemical cataract	Pigment enhancement Photosensitivity Skin burns
Ultraviolet A (315nm~400nm)			
Visible (400nm~780nm)		Photochemical and Thermal Retinal Damage	Skin burns
Infrared A (780nm~1400nm)		Cataracts, retinal burns	
Infrared B (1.4um~3.0um)		Anterior chamber flare, cataract, corneal burn	
Infrared C (3.0um~1mm)		Corneal burn	

Particularly dangerous wavelength range

750nm to 1400nm and around 400nm

Reaches retina
Low (no) sensitivity of the eye
makes it difficult to perceive
the threat of laser light and to
grasp the light path.



Nd:YAG, titanium sapphire lasers, and blue LDs
require caution

Example of laser accident (eye)

Cases	Age	laser	Year	Final vision
University Lecturer	34	Ruby	1965	1.5
Researcher	35	YAG	1975	0.06
Researcher	43	YAG	1987	0.1
—				
Graduate Student	23	YAG	1982	0.3
University student	22	YAG	1984	0.6
University student	21	Ti:S	2004	0.1(?)

Recently, a relative increase in the number of accident cases involving students at universities

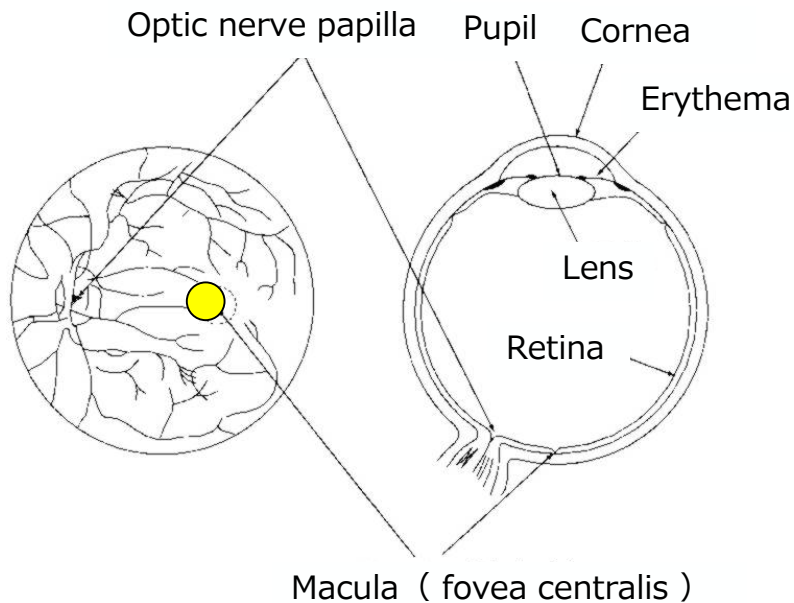
From 「Laser Safety Guidebook (New Technology Communication) 」
39 reported cases of accidents in Japan since the invention of the laser until 2005 (eye and skin)
(Alteration)

Vision loss is not correctable

Not a blessing in disguise if not blind !

Glasses and contacts do not restore vision !

Only the macula has a visual acuity of 1.2, which can be color resolved.



Photoreceptor cells are divided into brightness-sensitive rod cells and color-sensitive cone cells.

The macula has a high density of cone cells, and the center of the macula has the highest resolution in the visual field.



Except for the macula, low-resolution monochrome cameras

From 「Laser Safety Guidebook」

- View adjustment location
→ The image of the adjustment point is formed in the macula.
- Laser light coming from the alignment site.
→ The image remains in the macula.

This almost inevitably results in macular damage

Even if you see the same landscape.....



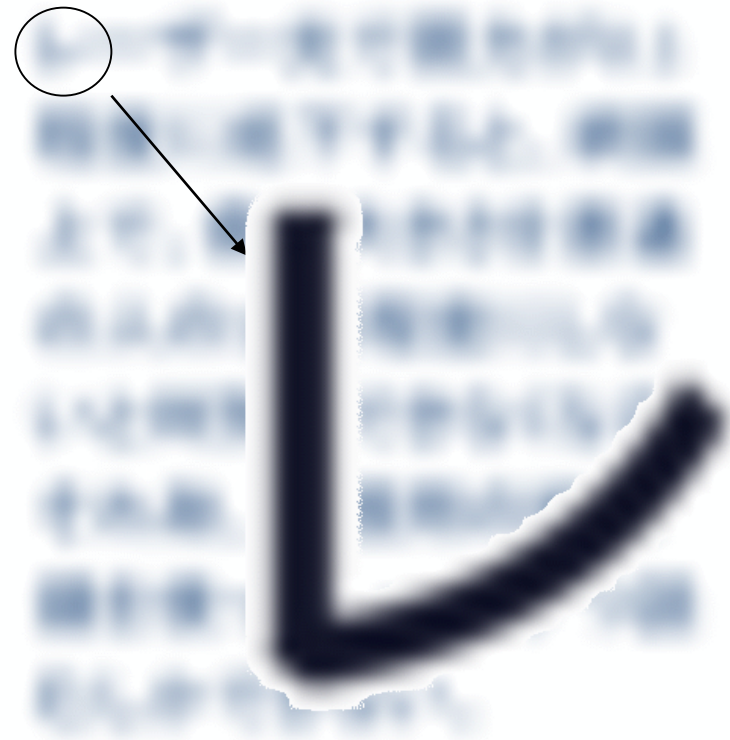
Cannot be corrected by glasses/contacts !!

Narrow real field of vision

Range of vision of 1.2

①レーザー光で視力が0.1程度に低下すると、網膜上で、像の大きさを普通の人の10倍程度にしないと判別ができなくなる。それ故、弱視用の拡大鏡を使って、一部ずつ読むしかできない。

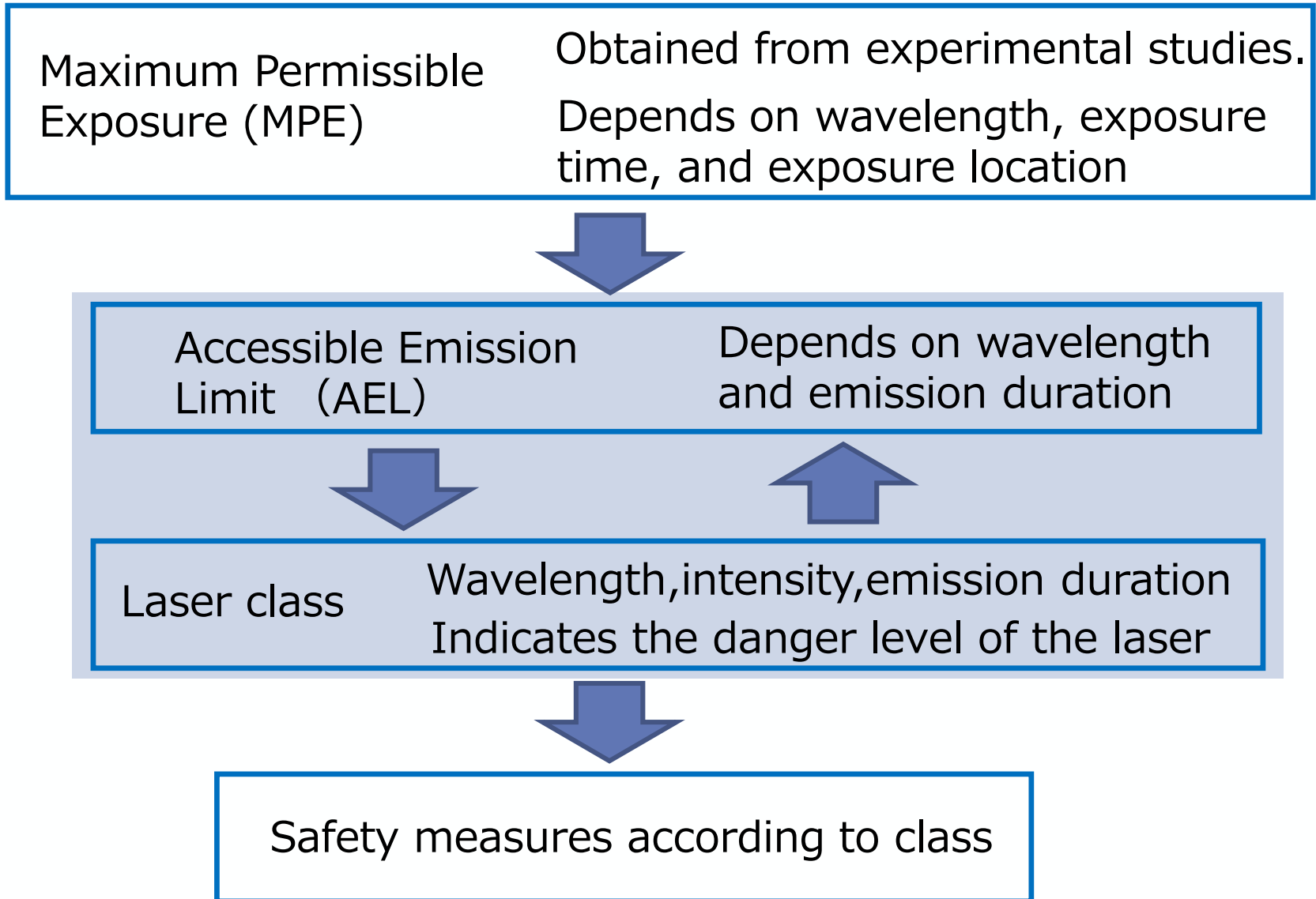
Range of vision of 0.1



To prevent eye damage

- Know the danger level of the laser you are using.
 - Classified according to the degree of danger
- If the laser you are using is highly dangerous, be sure to use the appropriate laser goggles.
(Protect yourself)
- Assemble the experimental system so that the laser beam does not go to unexpected places.
(Do not get others involved in accidents.)

Laser class, MPE, AEL



Classification of lasers

- Through laser accident cases, etc., **Maximum Permissible Exposure (MPE)** is defined.
- Accessible Emission Limit (ALE) that separate each laser from a safe phase to a very dangerous phase based on MPE are defined.
- The higher the class number, the greater the danger.
(Class 1 to Class 4)
 - **Classification is done by the manufacturer**
 - The user is responsible for safety management corresponding to the classification.
- Classification was (partially) changed in 2005.

Maximum permissible exposure (MPE)

The level of laser radiation that will **not cause harmful effects on the human body** under normal environmental conditions.

- 1/10 of the strength that results in a 50% probability of failure.
- Determined by wavelength and exposure time.
 - Where is it absorbed in the eye?

The longer the exposure time, the smaller the MPE.

- Eye has a smaller value than skin (more than 2 orders of magnitude smaller)

MPE at 400 nm to 1400 nm

Wavelength λ (nm)	Exposure time t (s)					
	$10^{-13} \sim 10^{-11}$	$10^{-11} \sim 5 \times 10^{-6}$	$5 \times 10^{-6} \sim 13 \times 10^{-6}$	$13 \times 10^{-6} \sim 10$	$10 \sim 10^2$	$10^2 \sim 3 \times 10^4$
400~450	$3.8 \times 10^{-8} \text{ J}$	$7.7 \times 10^{-8} \text{ J}$	$7 \times 10^{-4} t^{0.75} \text{ J}$		$3.9 \times 10^{-3} \text{ J}$	$3.9 \times 10^{-5} C_3 \text{ W}$
450~500					$3.9 \times 10^{-3} C_3 \text{ J}$ 及び $3.9 \times 10^{-4} \text{ W}$	
500~700					$3.9 \times 10^{-4} \text{ W}$	
700~1050	$3.8 \times 10^{-8} \text{ J}$	$7.7 \times 10^{-8} C_4 \text{ J}$	$7 \times 10^{-4} t^{0.75} C_4 \text{ J}$		$3.9 \times 10^{-4} C_4 C_7 \text{ W}$	
1050~1400	$3.8 \times 10^{-8} C_7 \text{ J}$	$7.7 \times 10^{-7} C_7 \text{ J}$		$3.5 \times 10^{-3} t^{0.75} C_7 \text{ J}$		

- Appropriate aperture must be used to calculate exposure (limiting aperture)
- For 400-1400 nm, use an aperture (pupil diameter) of 7 mm.
- C_n is the correction factor depending on wavelength. (JIS C6802:2014 Table 9.)

Maximum permissible exposure (MPE)

~MPE may be reviewed~

The standard was supposed to be a 10x safety factor

- Femtosecond lasers have reported failures with light weaker than MPE.
- Unconventional damage patterns
- Titanium Sapphire Lasers Require Caution

Even with chemicals, toxicity is often found later.

~Acute and chronic damage~

There are acute and chronic effects on the human body.

- Chemicals
 - Acute: Acids and alkalis
 - Chronic: Carcinogens, asbestos
- Light
 - Acute: Laser-induced blindness
 - Chronic: Skin cancer and cataract due to ultraviolet light

※ Caution against high-pressure mercury lamps, deuterium lamps, and ultraviolet LED light.
May cause delayed damage (cataracts, age-related macular degeneration, etc.)

Accessible Emission Limit (AEL)

Class 1 and Class 1M

Wavelength λ (nm)	Exposure time t (s)					
	$10^{-13} \sim 10^{-11}$	$10^{-11} \sim 5 \times 10^{-6}$	$5 \times 10^{-6} \sim 13 \times 10^{-6}$	$13 \times 10^{-6} \sim 10$	$10 \sim 10^2$	$10^2 \sim 3 \times 10^4$
400~450	$3.8 \times 10^{-8} \text{ J}$	$7.7 \times 10^{-8} \text{ J}$	$7 \times 10^{-4} t^{0.75} \text{ J}$		$3.9 \times 10^{-3} \text{ J}$	$3.9 \times 10^{-5} C_3 \text{ W}$
450~500					$3.9 \times 10^{-3} C_3 \text{ J}$ and $3.9 \times 10^{-4} \text{ W}$	
500~700					$3.9 \times 10^{-4} \text{ W}$	
700~1050	$3.8 \times 10^{-8} \text{ J}$	$7.7 \times 10^{-8} C_4 \text{ J}$	$7 \times 10^{-4} t^{0.75} C_4 \text{ J}$		$3.9 \times 10^{-4} C_4 C_7 \text{ W}$	
1050~1400	$3.8 \times 10^{-8} C_7 \text{ J}$	$7.7 \times 10^{-7} C_7 \text{ J}$		$3.5 \times 10^{-3} t^{0.75} C_7 \text{ J}$		

Class 2 and Class 2M

Wavelength λ (nm)	Exposure time t (s)	Class 2 AEL
400~700	$t < 0.25 \text{ s}$	Same as Class 1 AEL
	$t \geq 0.25 \text{ s}$	$C_6 \times 10^{-3} \text{ W}$

Target visible light from $\lambda = 400$ to 700 nm

Power level of 1 mW where hazards are avoided by the eye's aversion reaction (about 0.25 seconds)

Accessible Emission Limit (AEL)

Class 3R

Wavelength λ (nm)	Exposure time t (s)					
	$10^{-13} \sim 10^{-11}$	$10^{-11} \sim 5 \times 10^{-6}$	$5 \times 10^{-6} \sim 13 \times 10^{-6}$	$13 \times 10^{-6} \sim 0.35$	$0.35 \sim 10$	$10 \sim 3 \times 10^4$
400~700	$1.9 \times 10^{-7} \text{ J}$	$3.8 \times 10^{-7} \text{ J}$	$3.5 \times 10^{-3} t^{0.75} \text{ J (} t < 0.25 \text{ s)}$ $5.0 \times 10^{-3} \text{ W (} t \geq 0.25 \text{ s)}$		$5.0 \times 10^{-3} \text{ W}$	
700~1050	1					$2.0 \times 10^{-3} C_4 C_7 \text{ W}$
1050~1400	1.					

Class 3B

Wavelength λ (nm)	
400~700	
700~1050	
1050~1400	

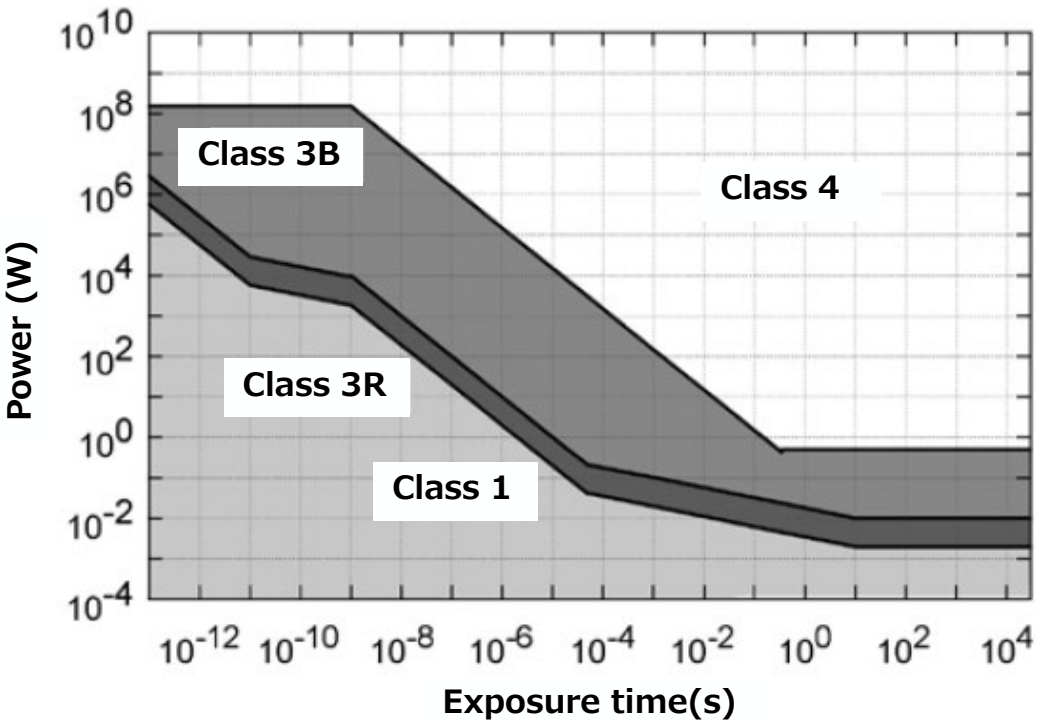


Fig.3 Nd:YAG laser Accessible Emission Limit (AEL)

Laser Class and Danger Level

- If you are using only Class 1, Class 1M, Class 2, or Class 2M, don't worry too much.
- If there is a Class 3R, you need to be careful.
- If you are using Class 3B or Class 4 lasers, be very careful.
 - If a Class 3B laser gets into your eye, it will almost certainly cause visual damage. A class 4 laser will cause visual damage if the reflected light gets into the eye.These lasers require a key to activate.

Be careful with lasers that have keys on the device.

Some imported laser pointers are even class 3B or 4.

Laser Classification

Class1	Safe under reasonably foreseeable conditions.	Lasers that can only produce less than MPE. According to the definition of MPE, it will not cause acute damage to the eye if kept in contact with the eye. Chronic damage is not guaranteed.
Class2	Safe because the eye is protected by aversion reactions such as blinking.	Lasers with power output not exceeding the MPE at 0.25 seconds. Only at 400-700nm, the laser has a higher value than Class 1. At other wavelengths, the eye is not protected and the laser is the same as Class 1.
Class3R	Direct in-beam observation can be dangerous.	Lasers with power less than 5 times greater than Class 2 Exceeds the MPE value, but is still within half the intensity of a 50% damage rate. For invisible wavelengths, laser goggles should be used. Goggle use is desirable even at visible wavelengths.
Class3B	Direct in-beam observation is usually hazardous.	Lasers of 0.5W or less (for visible CW) Should be considered as impairing when directly in the eye. Also, for 100-200mW or higher, reflected light from glass is also dangerous. Laser goggles should be worn when using Class 3B in an unenclosed space.
Class4	Diffuse reflections can also be dangerous.	Direct eye exposure is hopeless. If reflected light from glass or other sources enters the eye, the probability of damage is high. Anyone within range of the laser beam must wear goggles. Ensure that the laser beam is confined to the experimental space to prevent accidents to people not involved in the experiment.

Class 1M, 2M

Standard for lasers with strong optical divergence
(dispersive light source)

(semiconductor lasers, fiber output, etc.)

Intense but safe for naked eye

For example, lasers that do not exceed the AEL for each class at a distance of 10 cm from the source in the corneal transit area wavelength band and whose total power is less than Class 3B.

If the aperture transmitted power exceeds the AEL when a 5 cm diameter aperture is installed (if it does not exceed, it is not M).

Dangerous when parallel near a light source.

Dangerous if the light is concentrated by optics and put in the eye.

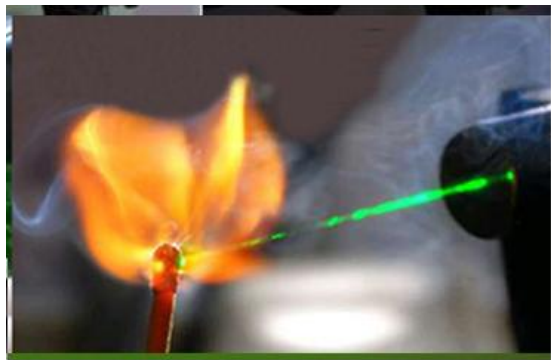
Dangerous if the focus is strong with near-sightedness and at 1 cm.

Laser Classification

- 1 mW green laser pointer
Class 1 AEL in CW is 0.39 mW, so class 2 or higher.
Class 3R AEL is 5 mW, so class 2.
- 10 mW He-Ne laser
Class 3R is 5 mW, so Class 3B or higher.
Class 3B AEL is 0.5 W, so Class 3B.
- YAG (1064nm) laser with 100mJ/pulse
at 5ns pulse width and 10Hz repetition rate
Class 3B AEL is 0.5W, so class 4.

Class 3 or higher laser pointer

- Illegal to sell in Japan
- Can be purchased online
 - (probably from an overseas vendor)
 - **Do not buy without thinking just because they are cheap.**
 - **Do not use them for academic presentations, etc.**
 - **Be careful of foreign souvenirs**
 - Be careful about domestic street sales



MPE with CW laser light

Ultraviolet LD	(350nm,10sec)	100 mW/cm ²
Ar Ion	(514.5nm,0.25sec)	1 mW
CW Green	(532nm,0.25sec)	1 mW
He-Ne	(632nm,0.25sec)	1 mW
Ti:S	(800nm,10sec)	0.65 mW
Nd:YAG	(1064nm,10sec)	2 mW
CO ₂	(10μm,10sec)	100 mW/cm ²

From MPE table and target wavelength and duration

$$7 \times 10^{-4} t^{0.75} [\text{J}] = 7 \times 10^{-4} 0.25^{0.75} \div 0.25 [\text{W}]$$

- ※ Value varies greatly depending on whether it reaches the retina.
- ※ Values at 0.25 sec for visible and 10 sec for the rest of the spectrum.

Important: It is only a guide, so do not take it for granted

MPE for pulsed laser light

Single-shot pulsed laser light

XeCl	(308nm,10nsec)	2 mJ
N ₂	(337nm,1nsec)	2 mJ
Nd:YAG SHG	(532nm,5ns)	77 nJ
Ti:S	(800nm,100fs)	38 nJ
Nd:YAG	(1064nm,5ns)	770 nJ

Continuous pulsed laser light

XeCl	(308nm,10nsec,50Hz)	1.2 mJ
N ₂	(337nm,1nsec,20Hz)	2 mJ
Nd:YAG SHG	(532nm,5ns,10Hz)	77 nJ
Ti:S	(800nm,100fs,80MHz)	8 pJ(0.65 mW)
Nd:YAG	(1064nm,5ns,10Hz)	770 nJ

※ All of the above values are for energy per pulse.

Ti:S is calculated with a duration of 10 seconds, and the others with a duration of 0.25 seconds.

※ For the MPE of pulsed laser light, compare the single-shot value with the continuous value and select the smaller value.

Important: Do not rely on this as a guide only.

Minimum Knowledge

- A 10mW visible continuous laser will almost certainly cause serious eye damage.
- Pulsed YAG is dangerous at 10 μJ /pulse.
- Femtosecond titanium sapphires are dangerous at a few mW.

Precautions for Class 3B and 4 lasers

- Use of laser goggles

- The best means of preventing eye damage

Personal and
Managerial Efforts

- Installation of optical table
and light shielding precautions

- Creating an environment where accidents are less likely to occur as a system

Management Efforts

- Precautions for optical adjustment

- Knowledge of how to protect your own eyes by yourself

Personal and
Managerial Efforts

The Role of the Manager and the Experimenter

- The Role of the Manager
 - Education and training
 - Establishment of an experiment system to prevent accidents
 - Key management
 - Classification of rooms
 - Purchase of goggles, etc.
 - Checking usage
- The Role of the Experimenter
 - Compliance with rules
In particular, wearing goggles
 - Learning safety knowledge
 - Pointing out problems in the system

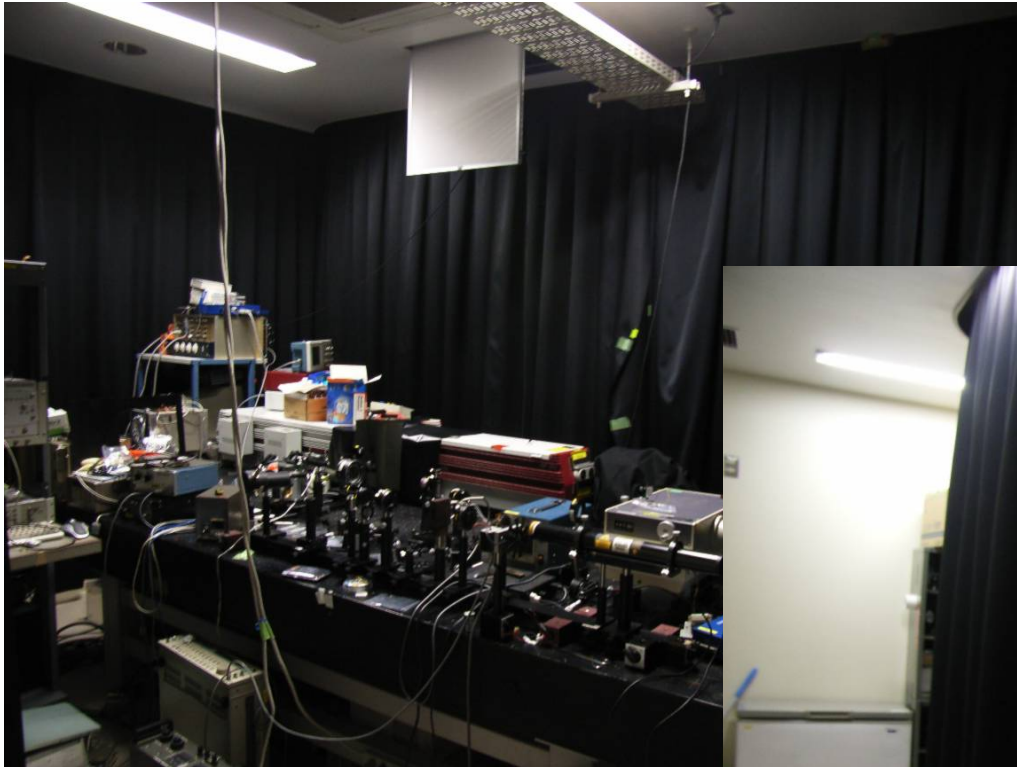
Knowledge and preparedness

Environment and Education



Ensuring safety as a system

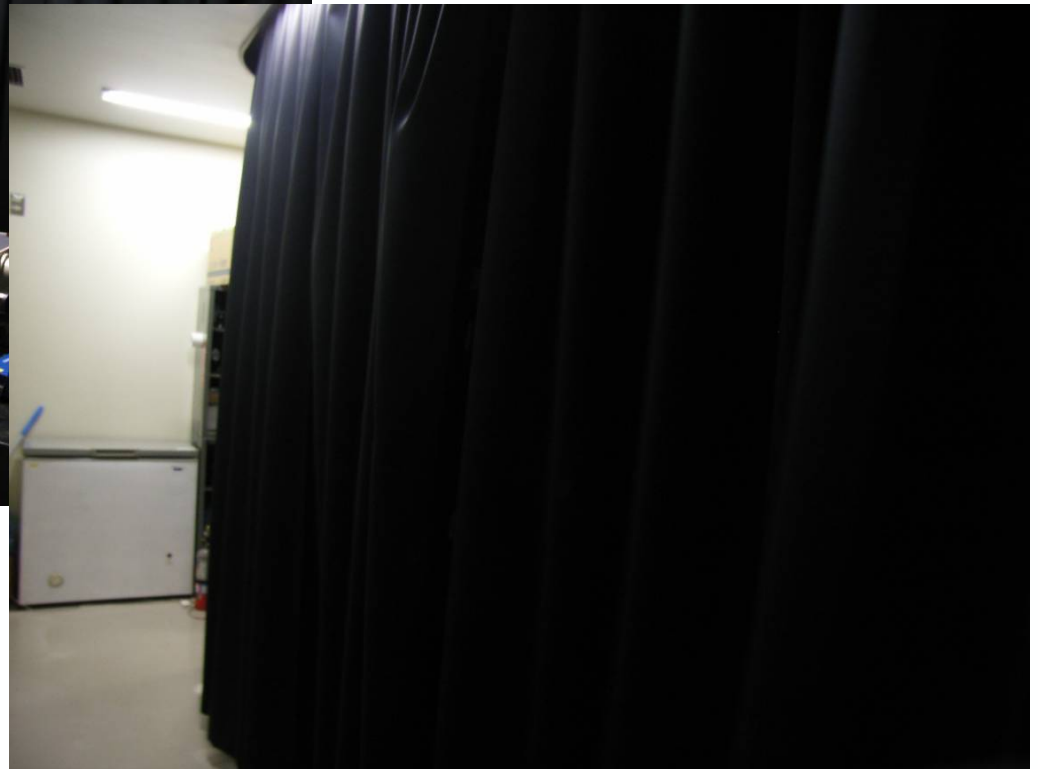
Separate rooms to confine light



← When not conducting experiments

↓ During experimentation

Further confine light
on an optical table



The most important point of accident prevention

There have been very few cases of eye injury accidents with goggles that are compatible with the laser being used.

- Excuses for not wearing goggles
 - No → This is the responsibility of the laboratory
 - Reduced operability
 - Makes you look like a beginner
 - I am careful not to cause accidents
 - I forget

Same as driving without a seatbelt

The worst thing that can happen in an accident is the person doing the experiment.

Use goggles that match your laser

Wearing goggles for different lasers does not help.



For argon lasers



For helium-neon lasers



For ultraviolet lasers



For YAG laser fundamental wave

Correct Laser Goggles

- Wavelength Selection
 - Accidents cannot be prevented without goggles that properly absorb the light of the wavelength being used
 - Be especially careful when multiple wavelengths are emitted, such as the fundamental and double wave of YAG
- Selecting the Optical Density
 - Light after transmission through goggles should be class 2 or less
 - For lasers in the visible range, there are goggles that allow a certain amount of laser light to pass through for adjustment (adjustment goggles).
Separate goggles for adjustment and goggles for protection should be used.
- Durability
 - Guarantee that the goggles can withstand a certain amount of laser radiation.
 - Colored sunglasses are not a substitute

Wavelength and optical density are indicated

Always indicate the optical density (OD) value at a given wavelength.
Check to see if the OD is sufficient for the laser wavelength you are using.



These goggles are for adjustment.
Transmits 1% of light at 514.5 nm.

A laser of several watts will definitely damage the eyes at direct incidence.

Transmittance and optical density (absorbance)

$$\text{Abs(OD)} = -\log\left(\frac{I}{I_0}\right)$$

OD value	Transmittance (%)
0	100
1	10
2	1
3	0.1

OD value of goggles required

CW { CW Green (532nm, 10W)
MPE is 1 mW, so 10W to less than 1 mW requires an attenuation factor of 1/10,000 → OD is 4 or higher

Nd:YAG (1064nm, 10W)
MPE is 2mW, so attenuation factor is 2/10,000
→ OD is 3.7 or higher

Pulse { Nd:YAG SHG (532nm, 100mJ)
MPE is 77 nJ, so OD is 6.2 or higher

Ti:S (800nm, 80MHz, 1W)
MPE is 0.65mW, so OD 3.1 or higher

Nd:YAG (1064nm, 500mJ)
MPE is 770 nJ, so OD 5.9 or higher

Important: This is only a guideline, so do not take it for granted.

Goggle type and sunglasses type



The goggle type (left) is safer because it can block light from any direction. Can be worn over eyeglasses.
Use the goggle type as much as possible (the drawback is that they sometimes fog up and are difficult to use...)

Adjustment goggles and protective goggles

- Adjustment goggles
 - Light attenuation is weak and laser light is visible even when worn.
- Protective goggles
 - Light attenuation is so strong that the laser light is (almost completely) invisible when worn.

Should wear protective class without distinction outside the visible range.

For special wavelengths and applications

- If there is no goggle that matches the laser/purpose you are using,
 - laser goggle catalogs have spectra, so find one that seems to fit and use it.
 - YAMAMOTO KOGAKU will respond to such inquiries.
- When using variable wavelength lasers, be careful not to deviate from the protective range of the goggles.
- When using multiple wavelength lasers at the same time,
 - use goggles that are compatible with all wavelengths used, if available.
 - If goggles that are compatible with all wavelengths are not available, then prioritize countermeasures for the most hazardous wavelengths (invisibility and high intensity), and provide beam protection for wavelengths not supported by the goggles.

If something happens...

- If you notice anything unusual, even if it is minor, see an ophthalmologist immediately (emergency room at night)
 - Corneal disorders are painful. Close your eyelids, rest your eyes, and go to an ophthalmologist immediately. If there is something nearby to cool the eye, you may cool it gently.
 - In some cases, retinal damage is painless. In this case also, close the eyelids and go to the ophthalmologist immediately. If there is pain, it may be okay to cool the eye gently.
 - People around the patient should take care to keep the patient calm.

※There is uncertainty about first aid before going to the ophthalmologist, so seek medical advice if necessary.

Acknowledgements :

Kondo Eye Clinic (Consultation Board April 2007)

For those who want to know more about it.

References you can rely on

「Laser Safety Guidebook」 (4th Edition)

New Technology Communications

The standard is JIS C680 2、C6803

Ministry of Health, Labour and Welfare Standard:

Measures to Prevent Hazards in Laser Beams

https://www.mhlw.go.jp/web/t_doc?dataId=00tc0756&dataType=1

Assembling Optics

- Design optical systems that reduce accident rates.
 - The more time it takes to adjust, the more accident rates increase.
- Reduce the likelihood of getting into the eye and the damage when it does.
 - Efforts to lower the accident rate
- Be careful when experimenting with multiple people and entering/exiting the laser experiment area.
 - Caution not to involve people

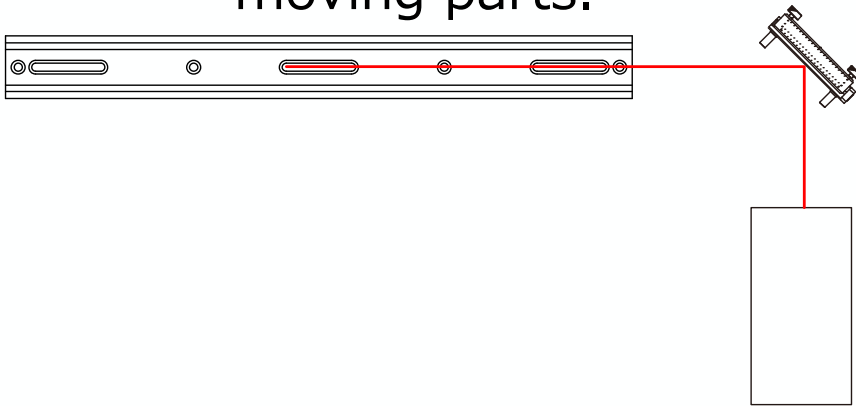
Accidents during adjustment are the most frequent

Rational optics design and adjustment

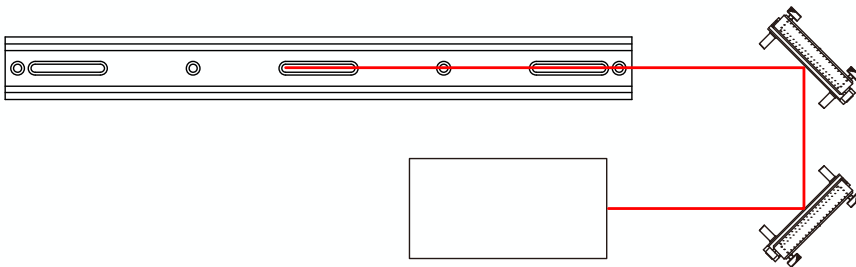
Arrangement for easy adjustment

Height and angle adjustment

- When adjusting optical path parallel to optical rails
 - Height and angle adjustment requires two or more moving parts.



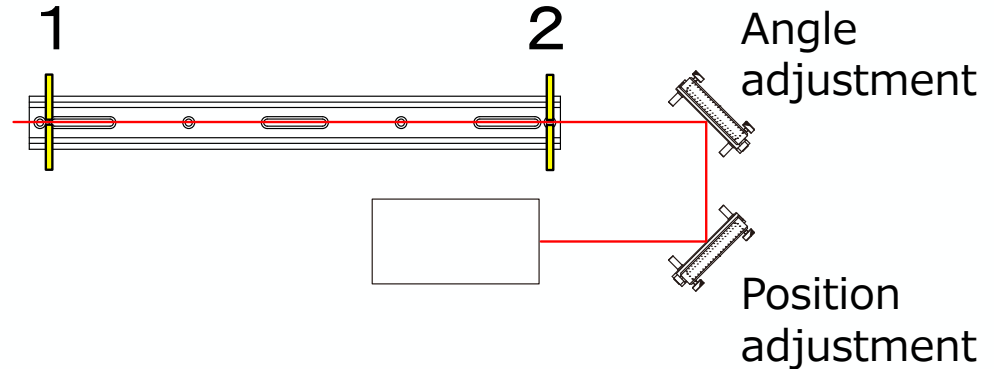
Adjustment is impossible unless the original laser is height and level.



Adjustment possible even if the height and level of the original laser are different.

Adjustment Procedure

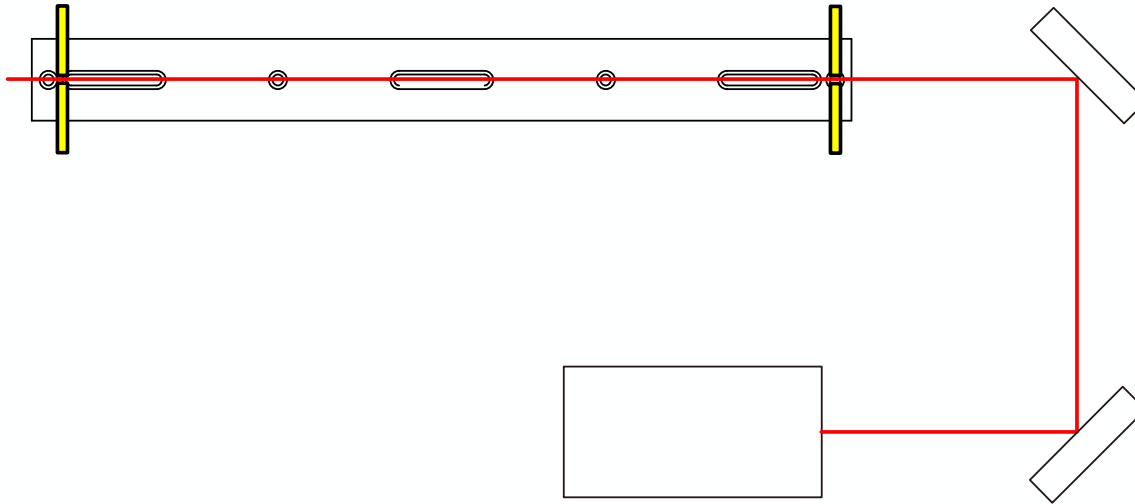
- Place the pinhole at 2 and adjust the position so that it passes through the pinhole.
- Place the pinhole at 1 and adjust the angle so that it passes through the pinhole.



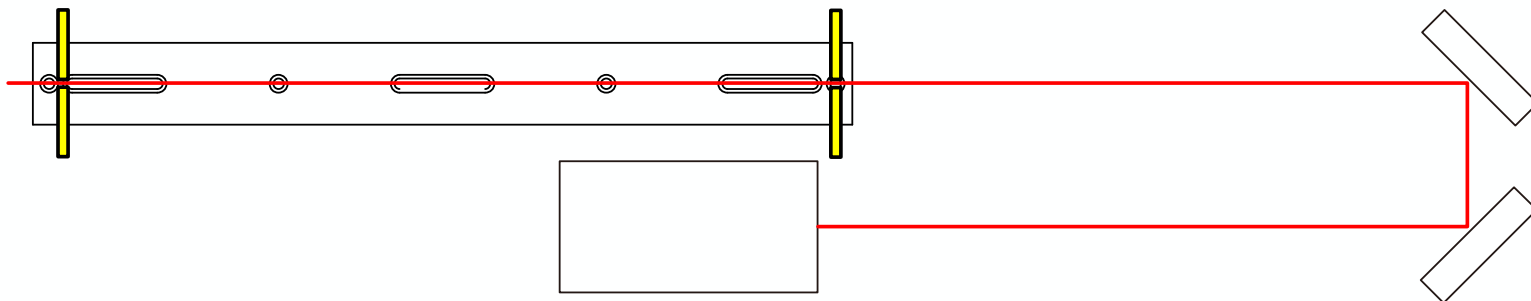
Repeat the above procedure until both pinholes are passed through.

※The concept is the same when using two lenses to spread light and send it straight ahead, etc.

Good and bad placement

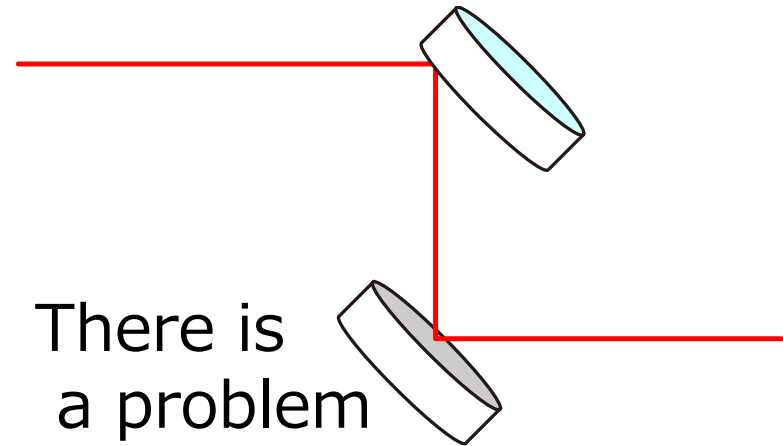
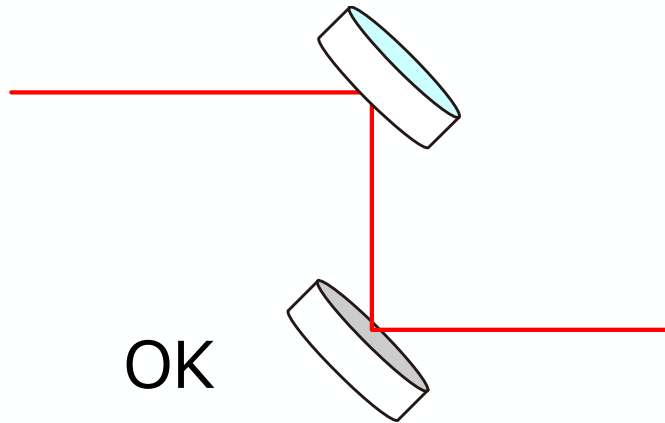


The roles of position and angle are clearly defined.



Roles of position and angle are not clear.

Passing light through the center of the optical element

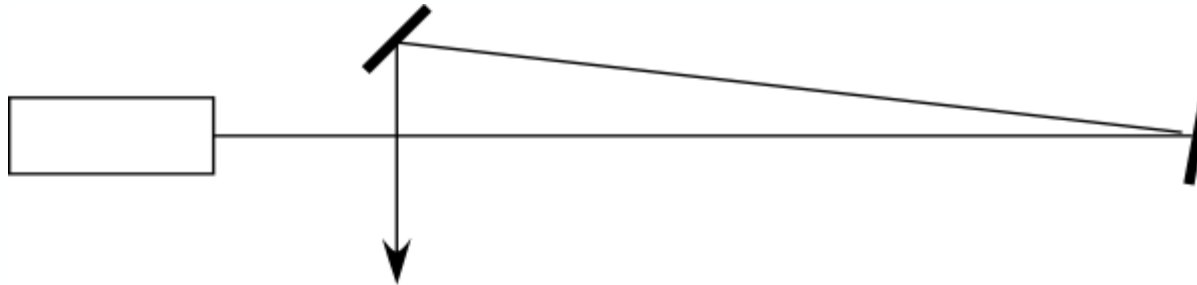


※At the edge of the mirror, light will fly in an unpredictable direction if it is off the edge of the mirror during the adjustment process.

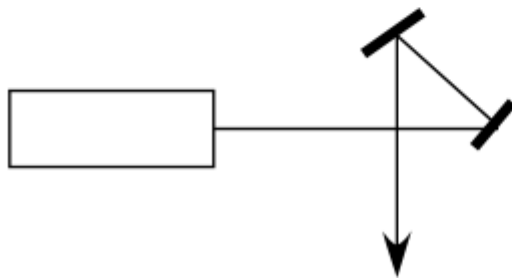
Check the position of the light during adjustment, and if it goes too far to the edge, readjust the mirror location.

In some cases, due to the thickness of the mirror, the edges must be used...

Light paths are compactly organized

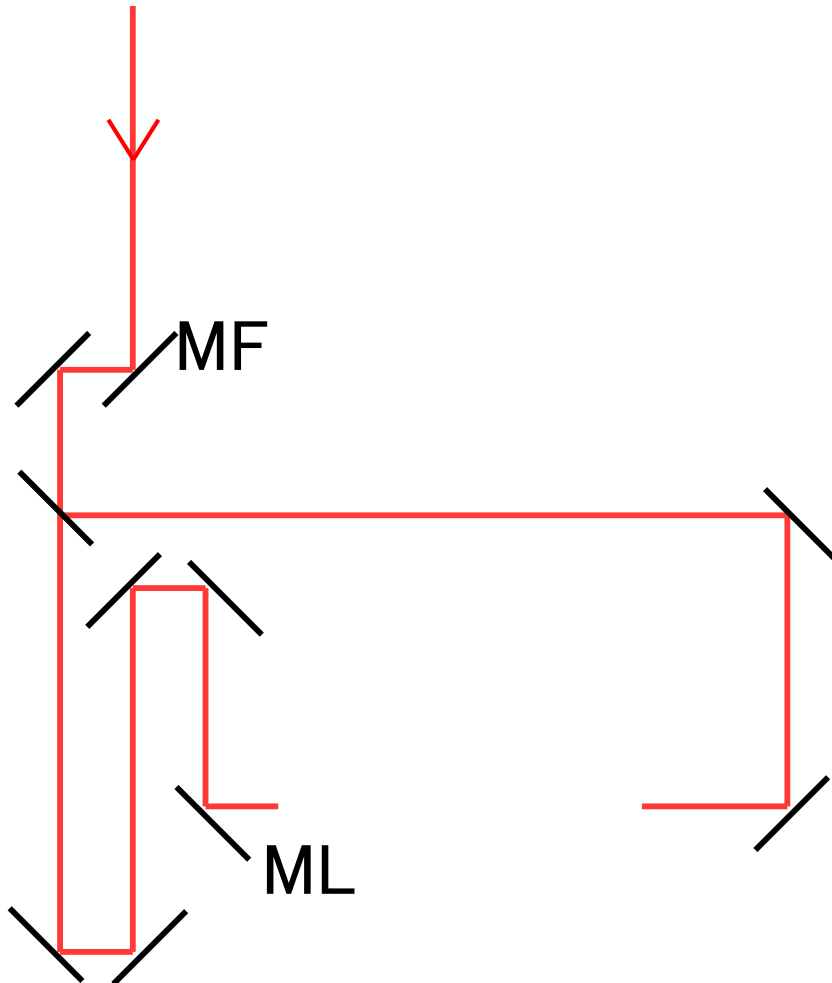


Lower setup is better unless there is a special reason.



- Longer optical path increases the rate at which objects enter the optical path.
- Longer optical path after the mirror makes it more vulnerable to vibration.

Adjustments are in order



Basically, adjustments are made from the light source side.

If the light source is properly aligned, there is no need to go back and correct it.

For example, if the MF is modified in the middle of the process, it will be necessary to redo everything after the MF.

Pinholes are placed at key points in the optical system to make it easier to see what is wrong.

Other Notes

Do not put light back into the laser

- If light is returned to the laser, an oscillation error will occur and oscillation will be unstable.
 - CW oscillation is unstable
 - Mode locks can fall off
 - Q-switched pulsed YAG can cause internal damage.

To allow the return light to be slightly shifted from the outgoing light.

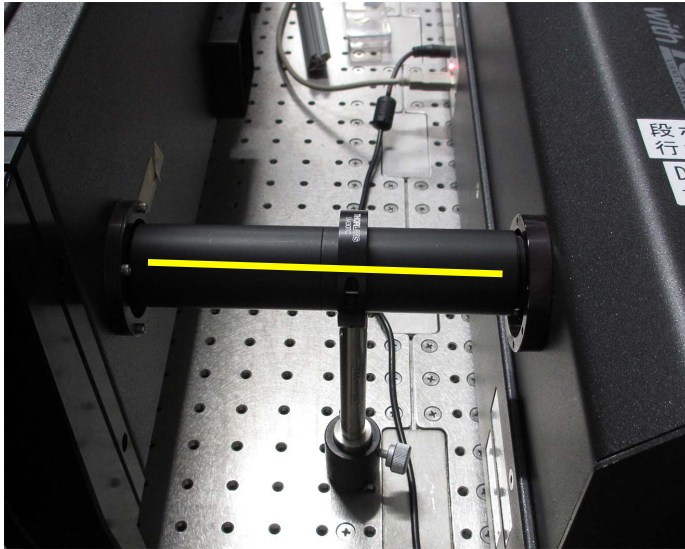
An optical isolator may be inserted.

Be careful not to damage optical elements

- Strong lasers can cause holes in metal mirrors, and absorptive filters can break due to heat.
 - Start with the weakest absorbing filter.
- In addition
 - When using high power lasers, the reflected light may be focused by polarizers, damaging the elements.

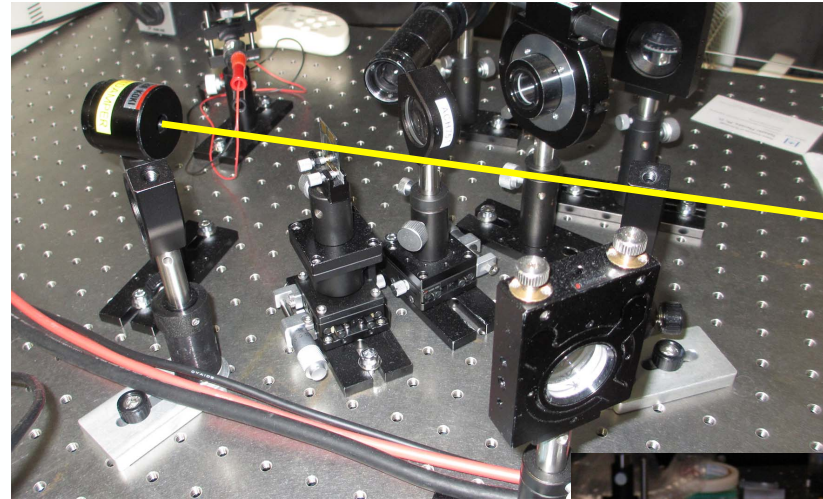
Shut out light

Protecting the optical path with a pipe



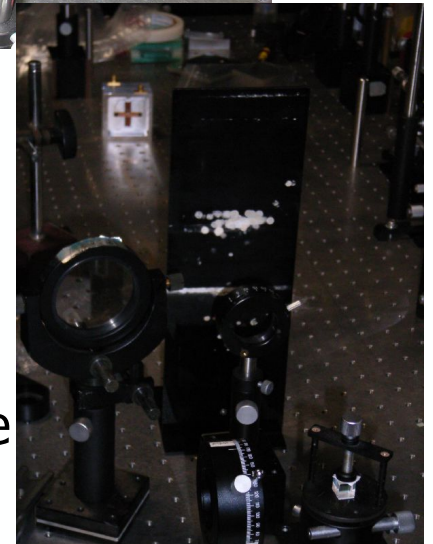
※Prevents objects from falling into the optical path during measurement.
Also effective in keeping out dust.

Stopping the light



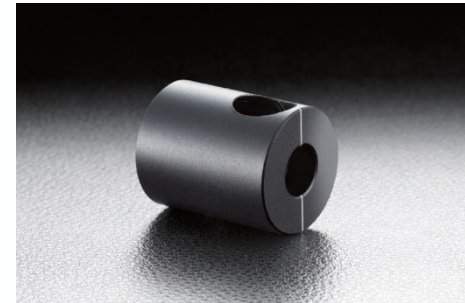
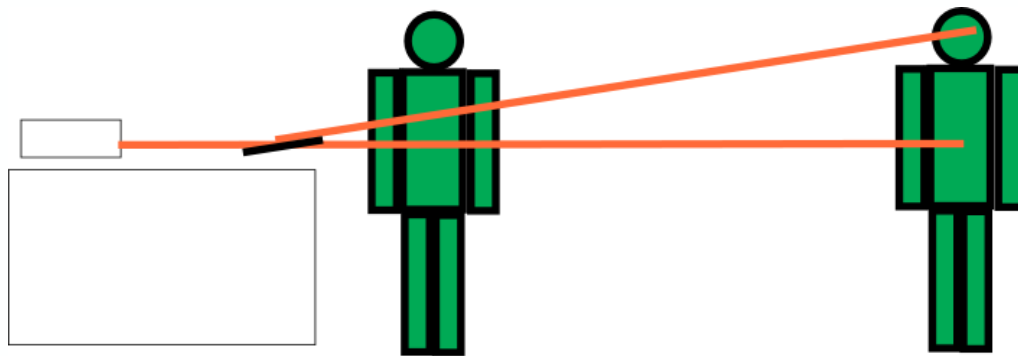
↑ Decent
Beam damper

→ This is...
a bad example



Laser beams are only flown horizontally

- If the laser light flies at an angle, the light goes to an unscheduled height when it flies outward.
- Treat the space above the optical table so that the laser does not fly into the space above the optical table as well (risk of getting in the eye when looking into it).



Gran laser prism with port

Reduces the possibility of getting into the eye and the damage when it does

Wear goggles

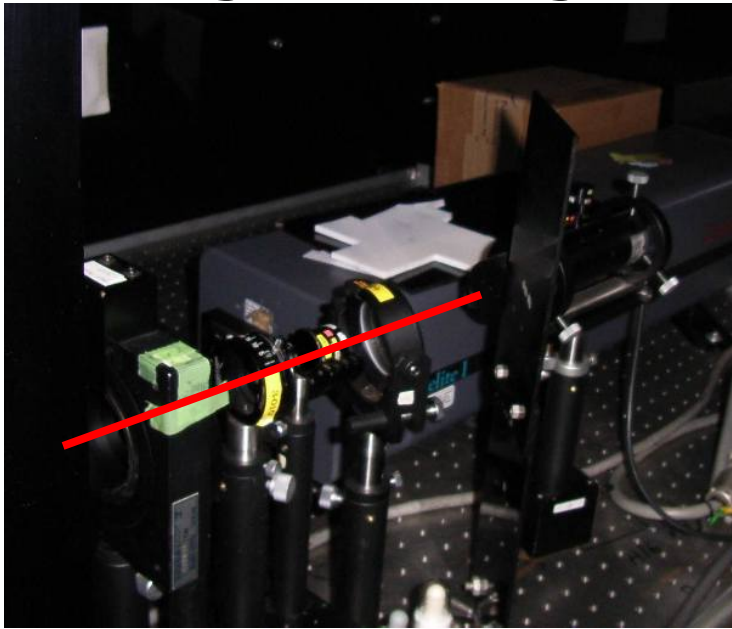
- Most basic technique to prevent laser accidents
- Always wear protective class goggles except for the person making the adjustment.

Use low power when adjusting

- Use low power when adjusting the optical axis (low power increases the chance of survival in the event of an accident).
- Reduce or block light when moving optics (unexpected reflections are more likely to occur during movement).
- He-Ne on coaxial for invisible lasers
- For lasers around 800 nm, use CCD video.

Reduces the possibility of getting into the eye and the damage when it does

Viewing invisible light

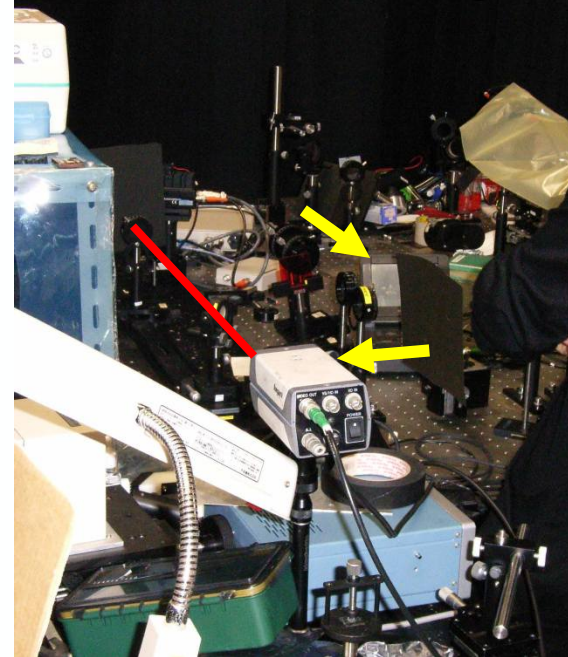


Coaxial with infrared light to fly visible light

Infrared viewer is also a necessity



Use video camera to adjust optics



Using a CCD camera sensitive to near-infrared, we can see the laser light with much higher sensitivity than the naked eye.

※ Some color video cameras have low near-infrared sensitivity. A monochrome camera would be OK.

Reduces the possibility of getting into the eye and the damage when it does

Do not darken the room

Size of human pupil
1mm (light place)

→7mm (dark place)

Pupil area is 50 times larger in the dark than in the light. So the probability of laser light passing through the pupil is also about 50 times.



Do not bring in reflective objects

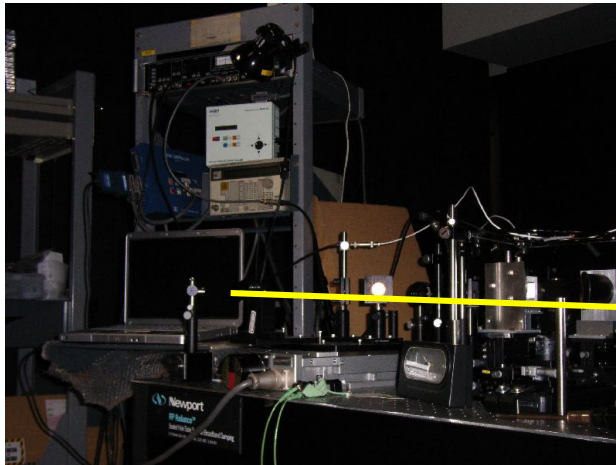
- Wristwatches and rings should be removed during the experiment because they cause unintended reflections.
- Use black tools whenever possible.
- Mirror surfaces (even black) should not be used for beam dampeners.
※ Cardboard is a fire hazard !



Do not work at the same height

as the laser beam

- Ensure that the height of the viewpoint when operating a computer, etc., does not overlap with the plane through which the laser passes (even if it is facing the opposite direction of the optical table).



※ In this case, the line of sight is slightly above the optical path. However, Depending on the angle and surface of the laptop screen, this can be dangerous.

※ Avoid situations where one person operates the PC while the other person works, especially

- When picking up an object that has fallen to the floor, crouch down facing away from the optical table so that your eyes do not cross the height of the light beam while facing the direction of the optical table

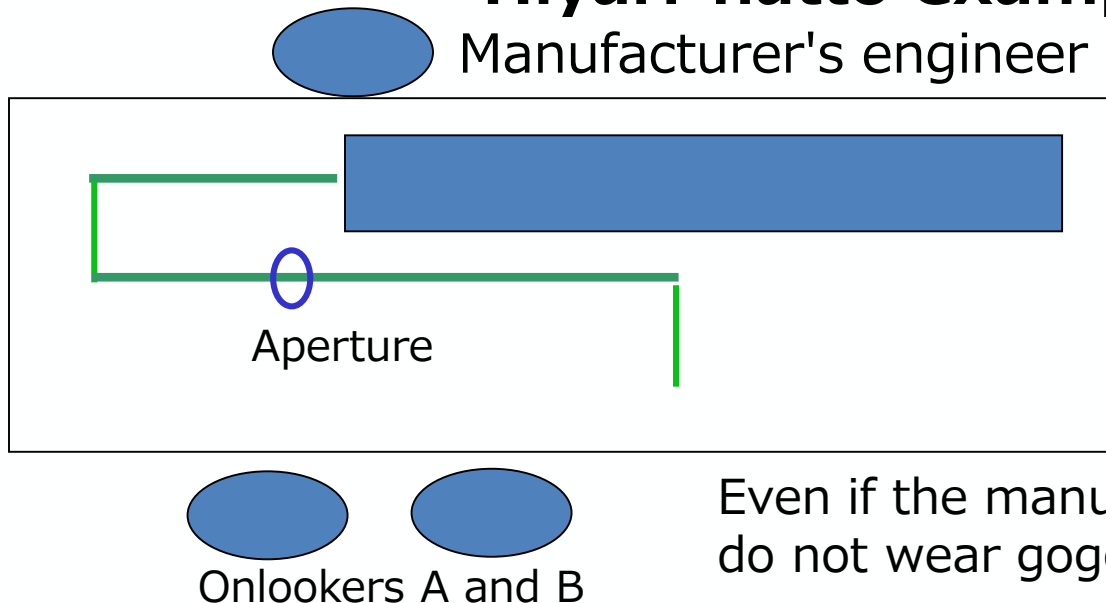
※ When light strikes a pole that is standing vertically, it will spread to the horizontal plane

Use extreme caution when working INSTITUTE of SCIENCE TOKYO

with more than one person

- When more than one person is working on a job, the probability of an accident is much higher than when only one person is working on a job.
 - Goggles are always worn except by the adjuster
 - Observers are more likely to be involved in accidents. Always wear goggles.
 - Always take at least two steps to unblock the laser
 - Blocking the laser light at multiple locations to prevent accidents from occurring even if someone makes a mistake in unblocking the laser light.

Hiyari-hatto example



Attach and detach the light path aperture while the manufacturer's engineer is adjusting it. At this point, light scattered by the aperture pole flew to the onlooker's side.

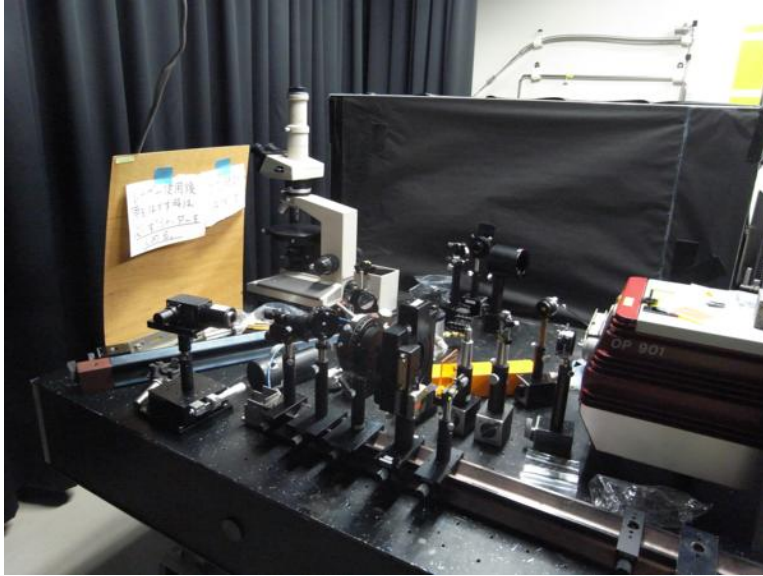
Even if the manufacturer's engineers do not wear goggles, onlookers do.

Be careful entering and exiting the laser experiment area (controlled area)

- If you cannot see what is going on beyond the blackout curtain, call out and check inside before opening the curtain (in principle, the controlled area is off-limits to all concerned parties).
- Prepare a "in use" sign so that it can be checked from the outside whether the laser is in use or not.
- When exiting, do not let the light out with you.



This is good at first

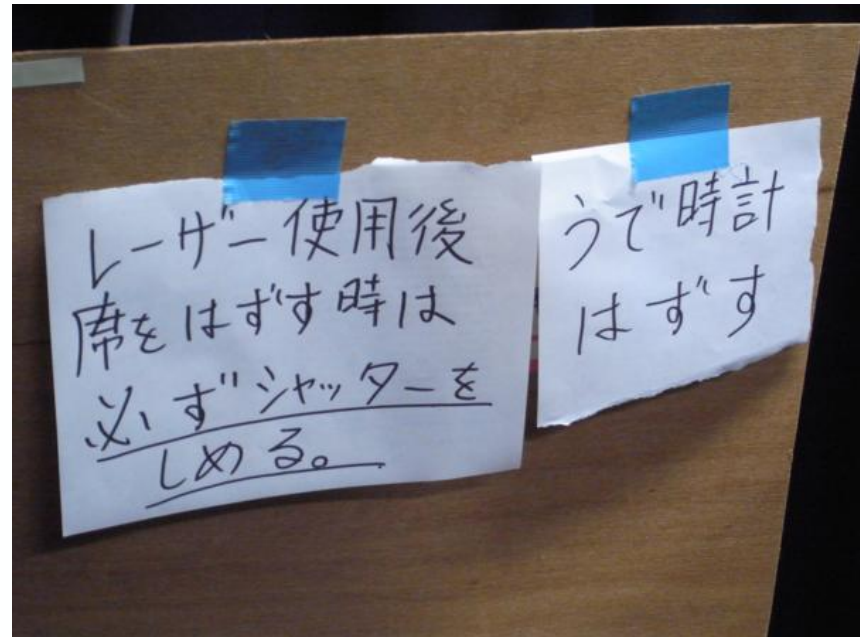


A good device to do it properly while you get used to it

In truth, posting a plywood and paper notice inside the controlled area is...

◆ But I'd like them to be able to avoid hazards naturally without this.

Because

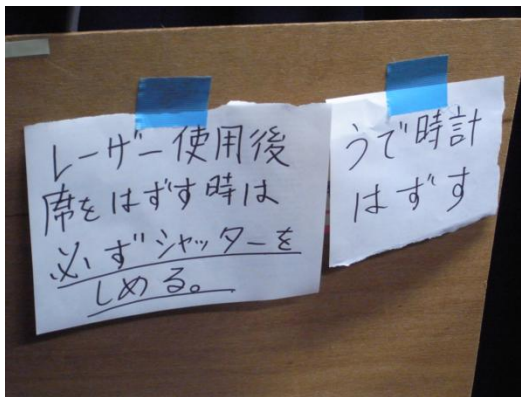


Because . . .

Once a human being has a reason to fail, he/she will continue to fail a thousand times with a hundred variations.

Makoto Tsuji

→ To reduce the number of failures, it is important to reduce the reasons for failure.



※ “Remove the watch from the wrist” is one of the variations of “do not bring a reflector into the optical path”.

Irregularities are bound to occur in experiments.

- When irregularities occur, you have to evaluate the risks and act on your own.
 - You need to understand the principle to judge whether it is safe or not, and to apply it.
 - The lab lore is quite often unfounded. You can follow it, but the damage is done to you.

How can we reduce the risk of eye damage
from laser accidents?

Have an accurate knowledge of the intensity of the damage to the eye and be able to talk about the specifications of the goggles needed to prevent it, including the reasons for the damage.

Thank you very much for your attention.