


MODULE 1-1

ELEMENTS AND OPERATION OF A LASER

(1) The laser is a light source that exhibits unique properties and a wide variety of applications. Lasers are used in welding, surveying, medicine, communication, national defense, and as tools in many areas of scientific research. Many types of lasers are commercially available today, ranging in size from devices that can rest on a fingertip to those that fill large buildings. All these lasers have certain basic characteristic properties in common.

(2) This module discusses the basic properties that distinguish laser light from other light sources and the essential elements required to produce this unique light. The lasing process is examined briefly, and several of the terms used to describe and characterize the process are introduced. In the laboratory section, the student will become acquainted with the basic safety procedures for the operation of a low-powered helium-neon gas laser and will identify the components of that laser.

(3) The student should take particular note that this module is designed to introduce all of the concepts to be studied in this course. Each topic covered here is discussed in greater detail in later modules.



OBJECTIVES

Upon completion of this module, the student should be able to:

- 1.1 Define the following properties of laser light:
 - 1.1.1 Monochromaticity.
 - 1.1.2 Directionality.
 - 1.1.3 Coherence.
- 1.2 Define the following terms that relate to the lasing process:
 - 1.2.1 Photon.
 - 1.2.2 Wavelength.
 - 1.2.3 Atomic ground state.
 - 1.2.4 Excited atomic state.

- 1.2.5 Population inversion.
- 1.3 Describe in a short paragraph and with a diagram the process of stimulated emission.
- 1.4 List the four elements of a laser, and state the purpose of each.
 - 4.1 Active Medium
 - 4.2 Excitation Mechanism
 - 4.3 Feedback Mechanism
 - 4.4 Output Coupler
- 1.5 Draw and label diagrams that illustrate the four basic elements of the following types of lasers:
 - 5.1 Helium-neon gas laser.
 - 5.2 Optically pumped CW solid laser.
 - 5.3 Flashlamp-pumped organic dye laser.
 - 5.4 Semiconductor laser.
- 1.6 List the seven safety precautions to be followed when operating a low powered, helium-neon gas laser.
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- 1 2 3 4 5 6 7
- 1.7 List the six steps in the operating procedure of a low-powered, helium neon laser.
- 1.8 Operate a helium-neon laser safely.
- 1.9 Remove the cover of a helium-neon laser, and draw and label its components.



PROPERTIES OF LASER LIGHT

(4) The light emitted by lasers is different from that produced by more common light sources such as incandescent bulbs, fluorescent lamps, and high-intensity arc lamps. An understanding of the unique properties of laser light may be achieved by contrasting it with the light produced by other, less unique sources.

MONOCHROMATICITY

(5) All light consists of waves traveling through space. The color of the

light is determined by the length of those waves, as illustrated in Figure 1.

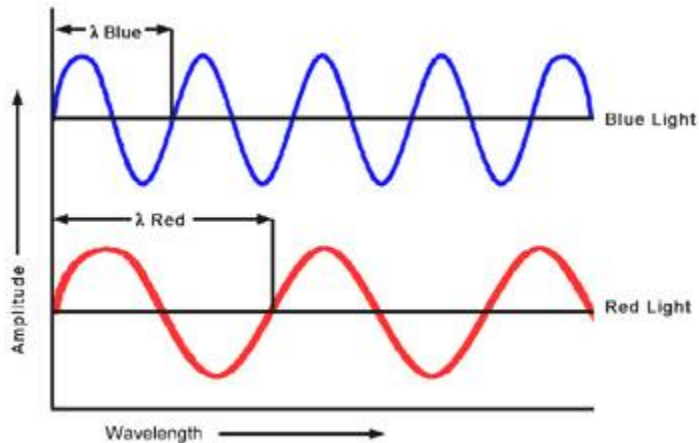


Fig. 1

Comparison of the wavelengths of red and blue light

(6) **Wavelength** is the distance over which the wave repeats itself and is represented by the Greek letter λ (lambda). Each color of visible light has its own characteristic wavelength.

(7) White light consists of a mixture of many different wavelengths. A prism can be used to disperse white light into its component wavelengths (colors), as in Figure 2.

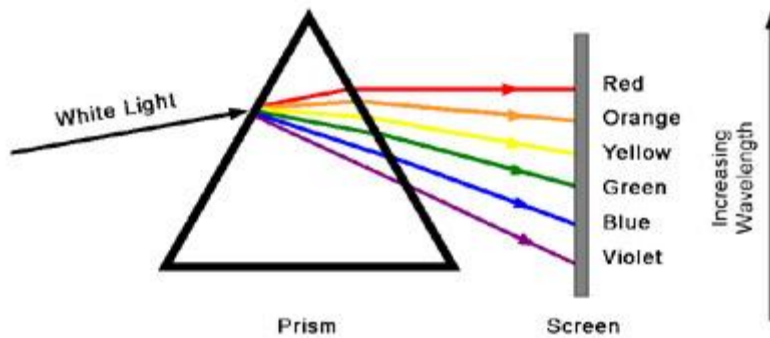


Fig. 2

Dispersion of white light by a prism

(8) All common light sources emit light of many different wavelengths. White light contains all, or most, of the colors of the visible spectrum. Ordinary colored light consists of a broad range of wavelengths covering a particular portion of the visible-light spectrum. A green traffic light, for example, emits the entire green portion of the spectrum, as well as some wavelengths in the neighboring yellow and blue regions.

(9) The beam of a helium-neon gas laser, on the other hand, is a very pure red color. It consists of an extremely narrow range of wavelengths within the red portion of the spectrum. It is said to be nearly "**monochromatic**," or nearly "single-colored." **Near**-monochromaticity is a unique property of laser light, meaning that it consists of light of almost a single wavelength. (Mike Leeming)

(10) Perfectly monochromatic light cannot be produced even by a laser, but laser light is many times more monochromatic than the light from any other source. In some applications, special techniques are employed to further narrow the range of wavelengths contained in the laser output and, thus, to increase the monochromaticity.

DIRECTIONALITY

(11) Figure 3 depicts light being emitted from a light bulb in all directions. All conventional light sources emit light in this manner. Devices such as automobile headlights and spotlights contain optical systems that collimate the emitted light, such that it leaves the device in a directional beam; however, the beam produced always diverges (spreads) more rapidly than the beam generated by a laser.



Fig. 3
Conventional source

(12) Figure 4 illustrates the highly directional nature of light produced by a laser. "**Directionality**" is the characteristic of laser light that causes it to travel in a single direction within a narrow cone of divergence.

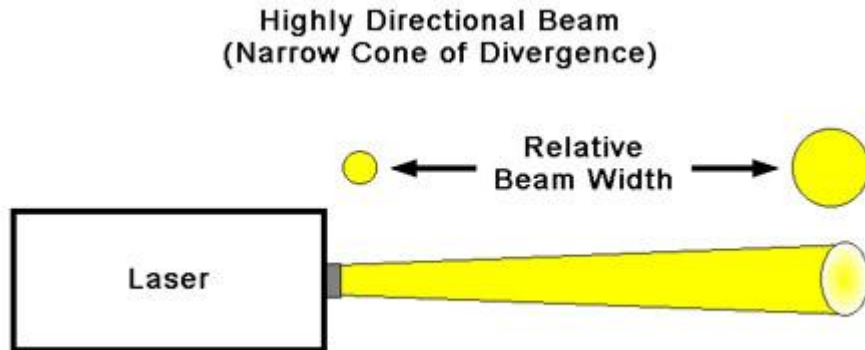


Fig. 4

Directionality of laser light

(13) But again, perfectly parallel beams of directional light—which we refer to as collimated light—cannot be produced. All light beams eventually spread (diverge) as they move through space. But laser light is more highly collimated, that is, it is far more directional than the light from any conventional source and thus less divergent. In some applications, optical systems are employed with lasers to improve the directionality of the output beam. One system of this type can produce a spot of laser light only one-half mile in diameter on the moon (a distance of 250,000 miles). (Mike Leeming)

COHERENCE

(14) Figure 5 depicts a parallel beam of light waves from an ordinary source traveling through space. None of these waves has any fixed relationship to any of the other waves within the beam. This light is said to be "incoherent," meaning that the light beam has no internal order. (Mike Leeming)

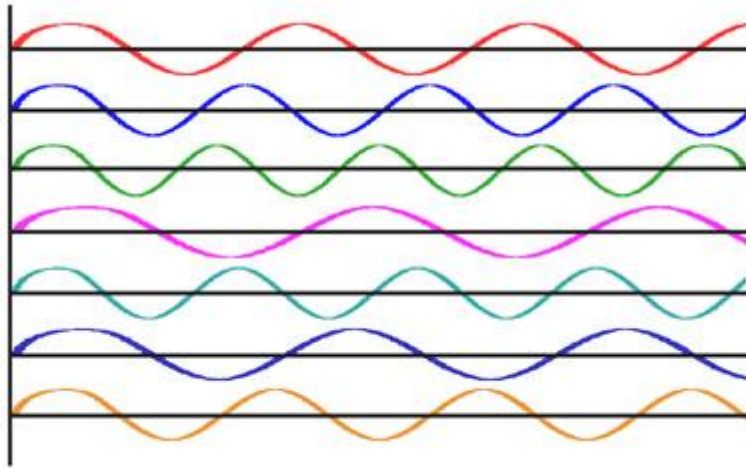


Fig. 5

Incoherent light waves

(15) Figure 6 illustrates the light waves within a highly collimated laser beam. All of these individual waves are in step, or "in phase," with one another at every point. "Coherence" is the term used to describe the in-phase property of light waves within a beam. (Mike Leeming)

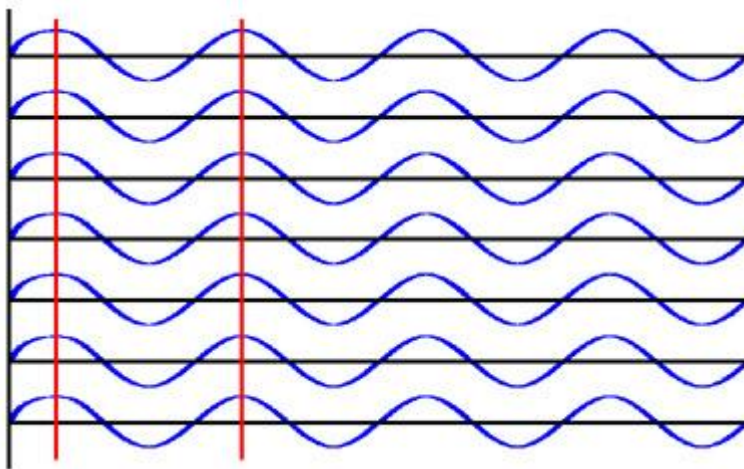


Fig. 6

Coherent light waves

(16) Just as laser light cannot be perfectly monochromatic or perfectly directional, it cannot have perfect coherence, yet laser light is far more coherent than light from any other source. Techniques currently in use greatly improve the coherence of light from many types of lasers.

(17) Coherence is the most fundamental property of laser light and distinguishes it from the light from other sources. Thus, a laser may be defined as a source of coherent light. The full importance of coherence cannot be understood until other concepts have been introduced, but

evidence of the coherence of laser light can be observed easily.

(18) In Figure 7, the beam of a low-powered laser strikes a rough surface, such as paper or wood, and is reflected in all directions. A portion of this light reaches the eye of an observer several meters away. The observer will see a bright spot that appears to be stippled with many bright and dark points. This "speckled" appearance is characteristic of coherent light, and is caused by a process called "interference," which will be discussed in a later module.

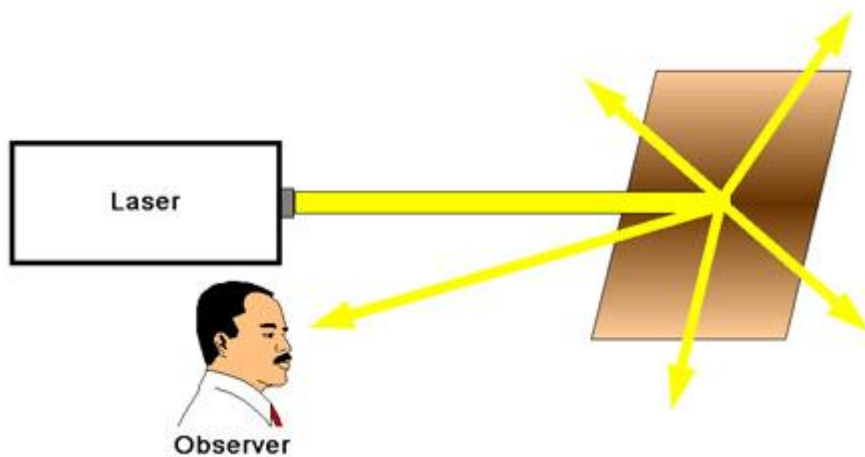


Fig. 7
Viewing laser speckle

EMISSION AND ABSORPTION OF LIGHT

(19) A laser produces coherent light through a process termed "stimulated emission." The word "**LASER**" is an acronym for "**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation." A brief discussion of the interaction of light with atoms is necessary before stimulated emission can be described.

ENERGY LEVELS IN ATOMS

(20) An atom is the smallest particle of an element that retains the characteristics of the element. An atom consists of a positive nucleus surrounded by a "cloud" of negative electrons. All neutral atoms of a given element have the same number of positive charges (protons) in the nucleus and negative charges (electrons) in the cloud. The energy content of atoms of a particular type may vary, however, depending on the energies contained by the electrons within the cloud.

(21) Each type of atom can contain only certain amounts of energy. When an atom contains the lowest amount of energy that is available to it, the atom is said to be in its "**atomic ground state.**" If the atom contains additional energy over and above its ground state, it is said to be in an "**excited atomic state.**"

(22) Figure 8 is a simplified energy-level diagram of an atom that has three energy levels. This atom can contain three distinct amounts of energy and no others. If the atom has an energy content of E_1 , it is in the atomic ground state and is incapable of releasing energy. If it contains energy content E_2 or E_3 , it is in an excited state and can release its excess energy, thereby dropping to a lower energy state. Real atoms may have hundreds or even thousands of possible distinct energy states. The three-level mode is utilized here for purposes of clarity.

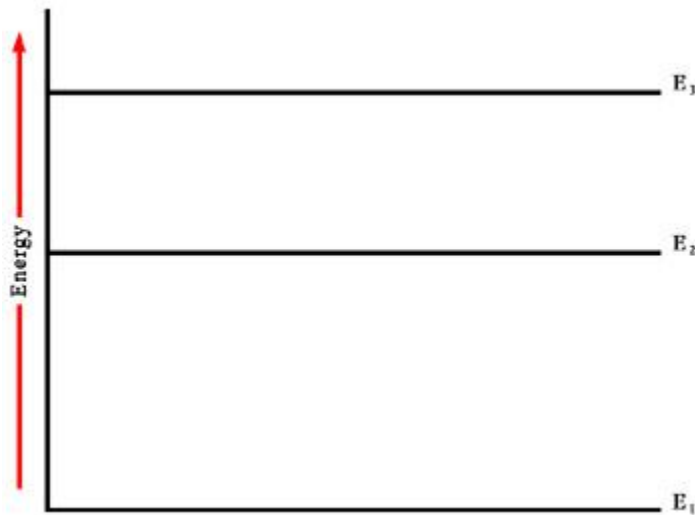


Fig.
Atomic energy-level diagram

8

SPONTANEOUS EMISSION OF LIGHT

(23) An atom in an excited state is unstable and will release spontaneously its excess energy and return to the ground state. This energy release may occur in a single transition or in a series of transitions that involve intermediate energy levels. For example, an atom in state E_3 of Figure 8 could reach the ground state by means of a single transition from E_3 to E_1 , or by two transitions, first from E_3 to E_2 and then from E_2 to E_1 . In any downward atomic transition, an amount of energy equal to the difference in energy content of the two levels must be released by the atom.

(24) In many cases, this excess energy appears as a photon of light. A **photon** is a quantum of light having a characteristic wavelength and energy content; in fact, the wavelength of the photon is determined by its energy. A photon of longer wavelength (such as that for red light) possesses less energy than one of shorter wavelength (such as that for blue light), as illustrated in Figure 9.

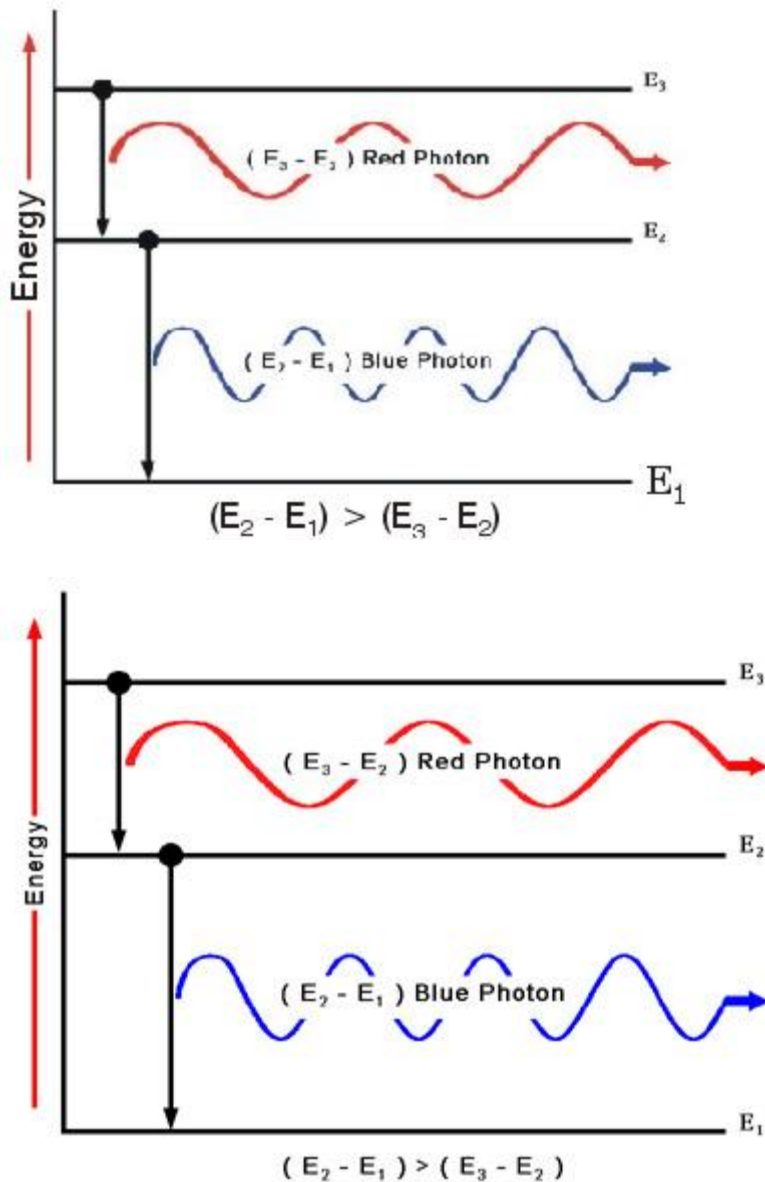


Fig. 9
Spontaneous emission

(25) In ordinary light sources, individual atoms release photons at random. Neither the direction nor the phase of the resulting photons is controlled in any way, and many wavelengths usually are present. This process is referred to as "spontaneous emission" because the atoms emit light

spontaneously, quite independent of any external influence. The light produced is neither monochromatic, directional, nor coherent.

STIMULATED EMISSION OF LIGHT

(26) The coherent light of the laser is produced by a "stimulated-emission" process (Figure 10). In this case, the excited atom is stimulated by an outside influence to emit its energy (photon) in a particular way.

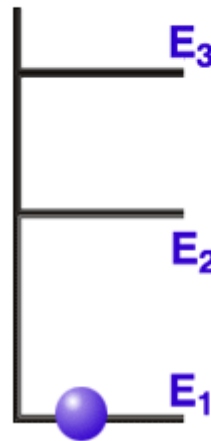


Fig. 10
Stimulated emission

(27) The stimulating agent is a photon whose energy ($E_3 - E_2$) is exactly equal to the energy difference between the present energy state of the atom, E_3 and some lower energy state, E_2 . This photon stimulates the atom to make a downward transition and emit, in phase, a photon identical to the stimulating photon. The emitted photon has the same energy, same wavelength, and same direction of travel as the stimulating photon; and the two are exactly in phase. Thus, stimulated emission produces light that is monochromatic, directional, and coherent. This light appears as the output beam of the laser. (Mike Leeming)

Note: Based on suggestions from Mike Leeming, this discussion on stimulated emission will be expanded in the revised version to be more detailed, will connect more closely with amplification, and will involve two diagrams for Figure 10, showing clearly the situation of photons/energy levels before interaction and photons/energy levels after interaction. (Mike Leeming)

ABSORPTION OF LIGHT

(28) Figure 11 illustrates another process that occurs within a laser. Here, a

photon strikes an atom in energy state E_2 and is absorbed by that atom. The photon ceases to exist; and its energy appears as increased energy in the atom, which moves to the E_3 energy level. The process of absorption removes energy from the laser beam and reduces laser output.

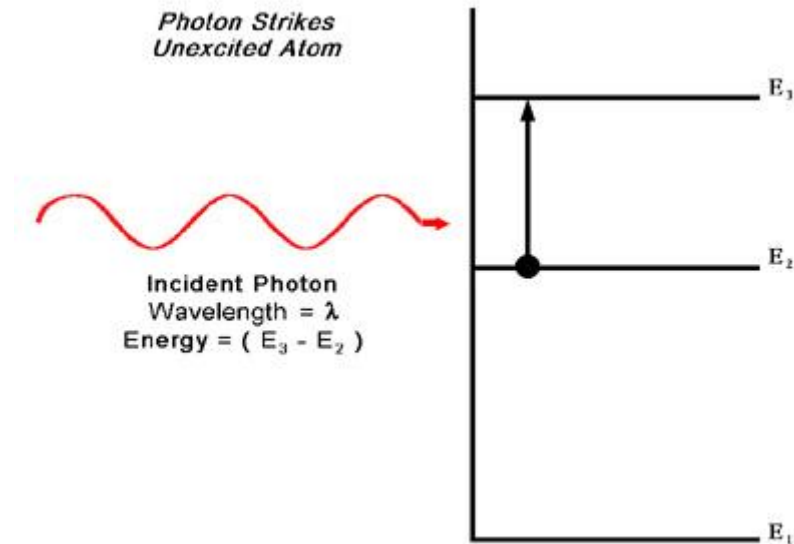


Fig. 11

Absorption of light

POPULATION INVERSION

(29) In order for a laser to produce an output, more light must be produced by stimulated emission than is lost through absorption. For this process to occur, more atoms must be in energy level E_3 than in level E_2 , which does not occur under normal circumstances. In any large collection of atoms in matter at any temperature T , most of the atoms will be in the ground state at a particular instant, and the population of each higher energy state will be lower than that of any of the lower energy states. This is called a "normal population distribution."

(30) Under "normal" circumstances, each energy level contains many more atoms than the energy level just above it, and so on up the energy lever ladder. For example, at room temperature, if there are N_0 atoms in the ground state of Neon (He-Ne laser) there are only $10^{-33}N_0$ atoms in the first excited state, even fewer in the second excited state and so forth. The population of the ascending energy levels decreases exponentially. (Mike Leeming)

(31) Thus, in any large collection of atoms in matter at any temperature T ,

most of the atoms will be in the ground state at a particular instant, and the population of each higher energy state will be lower than that of any of the lower energy states. This is called a "normal population distribution." (Mike Leeming)

(32) A **population inversion** exists whenever more atoms are in an excited atomic state than in some lower energy state. The lower state may be the ground state, but in most cases it is an excited state of lower energy. Lasers can produce coherent light by stimulated emission only if a population inversion is present. And a population inversion can be achieved only through external excitation of the atomic population.

ELEMENTS OF A LASER

(33) Four functional elements are necessary in lasers to produce coherent light by stimulated emission of radiation. Figure 12 illustrates these four functional elements.

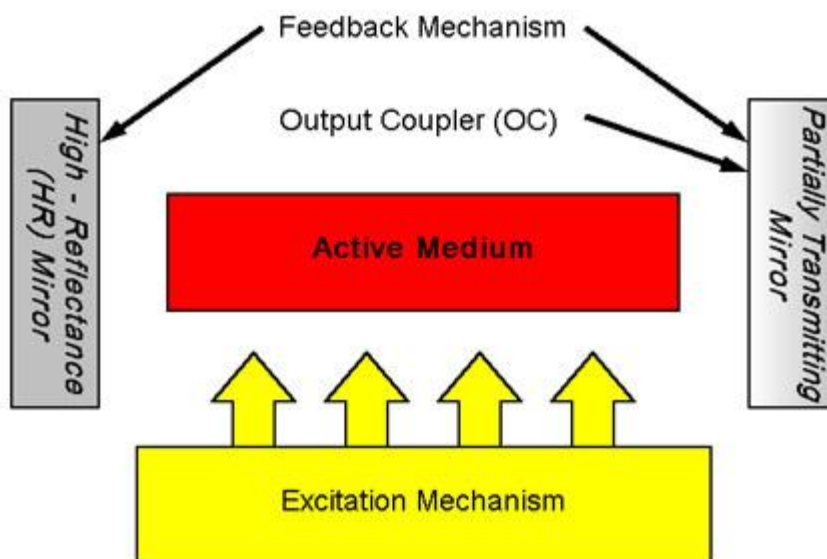


Fig. 12
Elements of a laser

ACTIVE MEDIUM

(34) The **active medium** is a collection of atoms or molecules that can be excited to a state of inverted population; that is, where more atoms or molecules are in an excited state than in some lower energy state. The two

states chosen for the lasing transition must possess certain characteristics. First, atoms must remain in the upper lasing level for a relatively long time to provide more emitted photons by stimulated emission than by spontaneous emission. Second, there must be an effective method of "pumping" atoms from the highly-populated ground state into the upper lasing state in order to increase the population of the higher energy level over the population in the lower energy level. An increase in population of the lower energy level to a number above that in the high energy level will negate the population inversion and thereby prevent the amplifications of emitted light by stimulated emission. In other words, as atoms move from the upper energy level to the lower energy level, more photons will be lost by spontaneous emission—giving off randomly directed, out-of-phase light—than gained due to the process of stimulated emission.) (Mike Leeming)

(35) The active medium of a laser can be thought of as an optical amplifier. A beam of coherent light entering one end of the active medium is amplified through stimulated emission until a coherent beam of increased intensity leaves the other end of the active medium. Thus, the active medium provides optical gain in the laser.

(36) The active medium may be a gas, a liquid, a solid material, or a junction between two slabs of semiconductor materials.

(37) A ruby crystal was the active medium of the first laser, invented by Dr. Theodore Maiman at the Hughes Laboratories in 1960. Liquid active media in tunable dye lasers consist of certain dyes dissolved in ethyl or methyl alcohol. Other active media include many types of gases and mixtures of gases. Lasers that contain a mixture of helium and neon gases or carbon dioxide gas are common examples of a gaseous active medium. A pn semiconductor junction, composed of gallium arsenide or gallium phosphide, is an example of yet another type of active medium.

EXCITATION MECHANISM

(38) The **excitation mechanism** is a source of energy that excites, or "pumps," the atoms in the active medium from a lower to a higher energy state in order to create a population inversion. In gas lasers and semiconductor lasers, the excitation mechanism usually consists of an electrical-current flow through the active medium. Solid and liquid lasers most often employ optical pumps; for example, in a ruby laser, the chromium atoms inside the ruby crystal may be pumped into an excited state by means of a powerful burst of light from a flashlamp containing xenon gas.

FEEDBACK MECHANISM

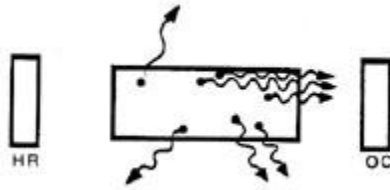
(39) The **feedback mechanism** returns a portion of the coherent light originally produced in the active medium back to the active medium for further amplification by stimulated emission. The amount of coherent light produced by stimulated emission depends upon both the degree of population inversion and the strength of the stimulating signal. The feedback mechanism usually consists of two mirrors--one at each end of the active medium--aligned in such a manner that they reflect the coherent light back and forth through the active medium.

OUTPUT COUPLER

(40)The **output coupler** allows a portion of the laser light contained between the two mirrors to leave the laser in the form of a beam. One of the mirrors of the feedback mechanism allows some light to be transmitted through it at the laser wavelength. The fraction of the coherent light allowed to escape varies greatly from one laser to another--from less than one percent for some helium-neon lasers to more than 80 percent for many solid-state lasers.

LASING ACTION

(41) When the excitation mechanism of a laser is activated, energy flows into the active medium, causing atoms to move from the ground state to certain excited states. In this way, population inversion is created. Some of the atoms in the upper lasing level drop to the lower lasing level spontaneously, emitting incoherent photons at the laser wavelength and in random directions. Most of these photons escape from the active medium, but those that travel along the axis of the active medium produce stimulated emission, as indicated in Figure 13. The beam produced is reflected back through the active medium by the mirrors. A portion of the light that strikes the output coupler leaves the laser as the output beam.

**Fig. 13**

Lasing begins.

-(43) If one keeps track of the number of photons in the beam during one round trip, say from HR to OC and back to HR, and the number of photons in the beam increases, the laser beam power increases. If the number is the same, the beam power is steady. If the number is less, the laser power decreases and eventually lasing stops. As we shall see later in more detail, the round-trip gain of the laser comes from the degree of population inversion in the active laser medium and the probability for a stimulated emission process to occur. The round-trip overall loss comes from imperfect reflection at the HR mirror, scattering and diffraction losses as the beam passes through the active medium absorption losses, cavity mirror misalignment losses, and of course, "the programmed" loss through the output mirror. When the gain for a round-trip exceeds the losses, laser power grows. When the round-trip gain is less than the losses, laser power dies out. And, when round-trip gain and loss are just equal, the laser operates in what we call a "steady-state" condition. (Mike Leeming)

(44) In pulsed lasers, the excitation mechanism supplies energy in short bursts. Both gain and output power rise quickly to a high level and drop off, producing a burst of laser light. In continuous-wave (CW) lasers, the excitation mechanism supplies a constant power to the active medium. The system quickly reaches a "steady-state" condition, in which loss and gain are in balance. This condition thereby results in a constant output beam.

TYPES OF LASERS

(45) Lasers may be classified according to the type of active medium, excitation mechanism, or duration of laser output. Classification by active medium is utilized here, but the examples given include both pulsed and CW lasers with electrical or optical pumping.

Note: M. Leeming suggests that we add material to this paragraph on typical applications of each "type" of laser and mention a few things on expense and safety issues. (Editor's Note: Does anyone out there have this information in convenient "table" format we can incorporate here?)

GAS LASERS

(46) A large and important family of lasers utilizes a gas or gas mixture as the active medium. Excitation usually is achieved by current flow through the gas. Gas lasers may be operated in either CW or pulsed modes.

(47) One popular type of gas laser contains a mixture of helium (He) and neon (Ne) gases and is illustrated in Figure 14. The gas mixture is contained at a low pressure within a sealed glass tube called the "plasma tube." The excitation mechanism of the HeNe laser is a direct-current discharge through the gas; the current pumps the helium atoms to an excited atomic state. The energy of the excited helium atoms is transferred to neon atoms through collisions, and the neon atoms then undergo a transition to a lower energy state that results in lasing. The feedback mechanism consists of a pair of mirrors sealed to the ends of the plasma tube. One of these mirrors, the output coupler, transmits 1-2 percent of the light to form a continuous (CW) output beam.

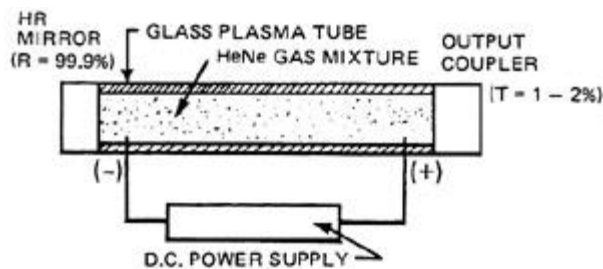


Fig. 14
HeNe gas laser

SOLID CRYSTALLINE AND GLASS LASERS

(48) Another important family of lasers contains solid crystalline or glass material as an active medium. Ruby and neodymium are two common examples of solid lasers with widespread industrial applications. Ruby is crystalline aluminum oxide in which some of the aluminum ions in the crystal lattice have been replaced by chromium ions. These chromium ions are the active elements in the ruby laser. Yttrium aluminum garnet (YAG) is the crystal host for Nd:YAG lasers; some of the aluminum in the YAG is replaced by triply-ionized neodymium (Nd^{3+}), a rare earth element. Glass is also used as a host for neodymium lasers.

(49) Figure 15 displays the components of a CW Nd:YAG laser. The active

medium is a cylinder of laser crystal whose ends have been cut parallel and polished. Antireflection coatings have been applied to the rod ends to reduce losses. The excitation mechanism for this particular laser is a tungsten filament lamp attached to an ac power source. Larger models utilize do krypton arc (gas discharge) lamps as pumping sources. Both types of lamps provide continuous optical pumping to the laser crystal. The mirrors of the Nd:YAG laser usually are mounted separately from the active medium as shown, but one of the mirror coatings sometimes is applied directly to one end of the rod.

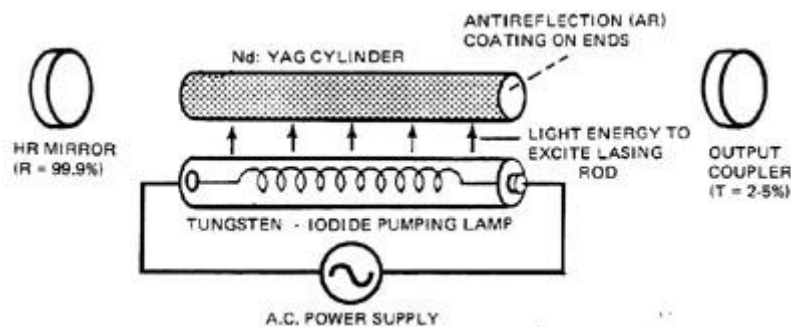


Fig. 15
CW Nd:YAG laser

(50) Pulsed Nd:YAG lasers have the same basic design, except that CW lamp and power supply are replaced by a xenon flashlamp and pulsed power supply. For example, if one replaces the tungsten-iodide discharge lamp in Figure 15 with either a Xenon flashlamp (as in Figure 16) or a pulsed laser diode, one can have re-rated pulsed laser operation in the place of CW operation. Ruby lasers are very similar in construction but are normally operated as pulsed lasers only. (John DeLeon)

(51) *Editor's Note:* John DeLeon called our attention to Figure 16, indicating that a change (update of laser system) is required. You will see that the figure and accompanying text have been changed in accordance with John's suggestion.

(52) Liquid dye lasers use a solution of a complex dye material as the active medium. The dyes are large organic molecules, with molecular weights of several hundred. Examples are rhodamine 6G and sodium fluorescein. The dye material is dissolved in an organic solvent, like methyl alcohol. Thus, the active medium is a liquid. Dye lasers are the only types of liquid lasers which have reached a well developed status. (John DeLeon)

LIQUID DYE LASERS

(53) Figure 16 shows a diagram of a typical design. The pump source is an argon laser, whose beam is focused to a small spot. The argon laser is a gas laser which emits blue and green light. The dye flows in a high velocity jet with the argon laser beam focused on the jet. The reasons for use of the jet will be discussed in a later course. The wavelength of the output is adjusted by the tuning element. The types of tuning elements available also will be described later. (John DeLeon)

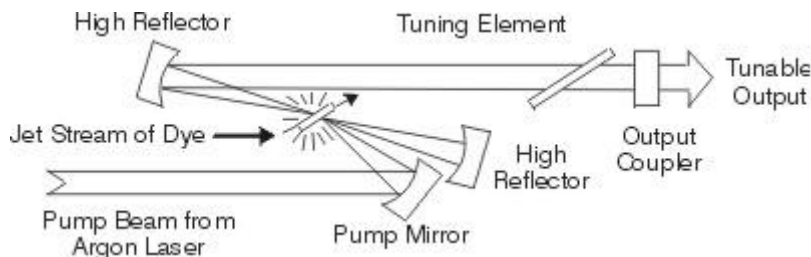


Fig. 16
Pulsed liquid dye laser

(54) One of the most important features that dye lasers offer is tunability, that is, the color of the output beam can be varied by adjusting the intercavity tuning element and also by changing the type of dye that is used. The monochromatic output of available dye lasers can be tuned over a broad range, from the ultraviolet, to the near infrared. Liquid dye lasers that can be tuned to any visible wavelength, and to portions of the infrared and ultraviolet, are commercially available in both pulsed and continuous models. Dye lasers are chosen for applications, like spectroscopy, in which tunability is important. (John DeLeon)

SEMICONDUCTOR LASERS

(55) The active medium of a semiconductor (injection) laser is the junction between two types of semiconductor materials.

(56) A semiconductor is a material whose electrical conductivity is greater than that of an insulator, such as glass or plastic, but less than that of a good conductor, such as silver or copper. Gallium arsenide (GaAs) is an example of a material used in the manufacture of a semiconductor laser. A p-type semiconductor material has a deficiency of negatively-charged free electrons in the crystal structure. This deficiency exists in the form of

positions in the crystal that can accept an electron if one were available. These positively-charged "holes" are the carriers of electric current in p-type semiconductors. By contrast, an n-type semiconductor material has a surplus of electrons that act as current carriers. If two slabs, one of p-type and one of n-type semiconductor material, are joined together, the result is called a pn junction. When current flows across a pn junction, free electrons from the n-type material combine with holes in the p-type material and release energy. This energy may appear as visible light as in the light-emitting-diode (LED) displays of electronic calculators.

(57) Figure 17 gives the construction of a semiconductor laser. The laser diode is a rectangular-shaped crystal of gallium arsenide that contains a pn junction. The entire device is about the size of a grain of sand. The end faces of the laser diode are "cleaved" along the crystal planes to form parallel reflection surfaces that act as the mirrors of the feedback mechanism. Current flow across the junction is the excitation mechanism. Semiconductor lasers usually have outputs in the infrared wavelength range, although some models that emit in the visible region are available.

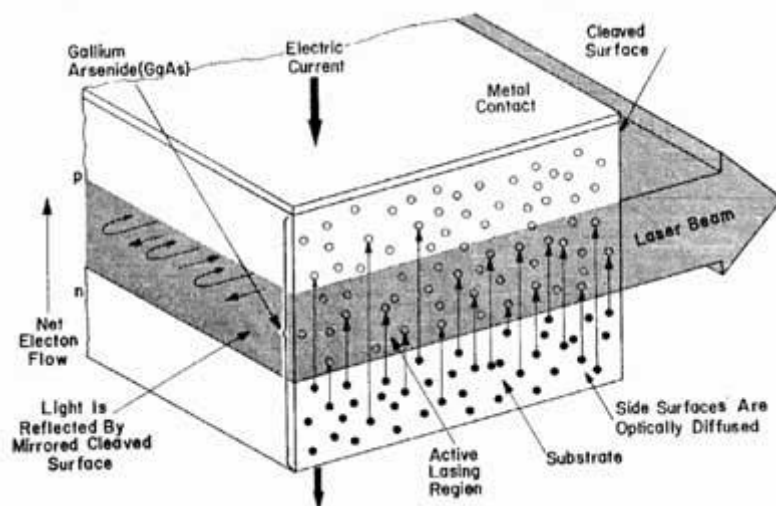


Fig. 17
Semiconductor laser (grossly enlarged)

SAFETY PRECAUTIONS FOR HELIUM-NEON LASERS

(58) The HeNe gas laser described previously is, by far, one of the most common types of lasers, and of historical importance, since it, along with the ruby laser, was one of the first to be built. HeNe lasers in the 0.5-mW to 5.0-mW range are common tools for alignment and science laboratories (1 milliwatt = 10^{-3} watt). Although these devices are safe if handled

properly, they can cause injury if employed improperly. The following procedures will ensure the safe operation of a HeNe laser. (Mike Leeming)

1. **DO NOT LOOK DIRECTLY INTO THE LASER BEAM.**
2. The low-power HeNe laser is little more than a coherent, monochromatic light bulb. The HeNe laser described here is not capable of burning or drilling holes in most materials; and accidental, momentary eye exposure will not normally cause eye damage. Nevertheless, the highlydirectional, intense beam of light should be treated with caution, care and respect. Common sense dictates that one must not look directly into any bright light source such as the sun, carbon arc, or an arc lamp projector, and particularly a laser beam. The lens of the eye can focus the beam from even a low-powered (1^{-5} mW) HeNe laser to a small spot on the retina and cause thermal damage to retinal tissue.
3. **DO NOT LOOK AT SPECULAR REFLECTIONS OF THE LASER BEAM.**
4. Specular reflections are those from mirrors, watch crystals, polished metal surfaces (painted and unpainted), or any other highlyreflective surface. Specular reflections of a laser beam are considered secondary laser sources and, as such, are treated with the same caution as is the direct laser beam. (See Laser Safety Precaution 1.)
5. **TAKE CARE WHEN MOVING THE LASER OR WHEN MOVING OBJECTS IN THE BEAM PATH OF THE LASER.**
6. Most low-power HeNe lasers are small enough to be moved about easily. If the laser must be moved during its operation, care must be taken to direct the beam carefully in order that it will not shine into anyone's eyes. For the reasons outlined in Laser Safety Precaution 2, caution also must be taken not to direct the beam upon a specular reflector when the laser is moved.

If an object must be moved into the beam of a laser, movement should be deliberate, with due consideration given to where the reflections will be directed. Usually, a laser should be turned off before it is moved.

7. **BEWARE OF HIGH VOLTAGE, ESPECIALLY WHEN THE CASE OR ENCLOSURE OF AN OPERATING LASER IS OPEN. (Mike Leeming)**
8. The HeNe laser described here contains a high-voltage power supply. This unit should not be disassembled, demonstrated, or serviced by anyone unfamiliar with such devices. Most lasers contain either high-voltage or high-current power supplies that should be treated with caution. Each year more people in the laser industry are injured by electrical hazards than by exposure to laser

beams.

9. **OPERATE THE LASER IN AN AREA DESIGNED FOR LASER OPERATION**

10. If possible, the laser should be operated with the beam horizontal and below eye level to prevent eye damage. All potential specular reflectors should be removed from the beam area. Adequate provision for all support equipment should be made prior to the operation of the laser. The number of persons working around the laser should be kept to a minimum, and the area at which the laser is being operated should be illuminated as much as possible. Access to the operation area should be limited and appropriate warning signs exhibited.

Most low-power HeNe lasers are designed to operate with 110/120 volts, single phase, 50-60 Hz ac power. Some may operate with 220/240 volts, single- or three-phase 50-60 Hz ac power. Prior to the operation of any laser, the correct power requirements for that laser should be determined from the laser specification. The power cord attached to the laser should be examined. For most low-power HeNe lasers, the unit is equipped with a power cord consisting of a three-wire, grounded plug. The third-wire, grounded terminal must not be bypassed.

11. **DO NOT INTENTIONALLY OR INADVERTENTLY TRACK VEHICLES OR AIRCRAFT WITH THE LASER BEAM.**

12. Federal laws prohibit the tracking of vehicles or aircraft with laser beams. Such actions could cause considerable property damage, loss of eyesight, or even loss of lives.
13. **DO NOT LEAVE AN OPERATING LASER UNATTENDED. ALWAYS UNPLUG IT WHEN IT IS NOT BEING USED.**
14. When not in use, the laser should be turned off to prevent accidental exposure to the beam by unqualified persons.

Note: Mike Leeming suggests that here, or in the safety precautions section, we provide references to appropriate ISO or ANSI safety standards. Also, he asks if there is a glossary of "safety-related" or standard labels such as the "caution" symbol included that we can add? (Editor's comment: Send us via FAX, sources or samples of labels you are currently using around the lab. Which ANSI standards do you cover with your students?)



EXERCISES

1. Define the following properties of laser light:
 - Monochromaticity
 - Directionality
 - Coherence
2. Define the following terms or phrases related to lasing action:
 - Atomic ground state
 - Excited atomic state
 - Population inversion
 - Wavelength
 - Photon
3. Describe stimulated emission with the aid of a diagram.
4. Draw and label a diagram that illustrates the four elements of a laser.
5. State the purpose of each element of a laser, using the concepts of stimulated emission and population inversion, and the principle of feedback.
6. Draw and label diagrams that depict the four elements of each of the following types of lasers:

- | | | | |
|----|------------------|-------------|--------|
| a. | CW | helium-neon | gas. |
| b. | Optically-pumped | CW | solid. |
| c. | Flashlamp-pumped | organic | dye. |
| d. | Semiconductor. | | |



MATERIALS

Block		of	Helium-neon	laser
Laser	specifications	or	operations	wood
Appropriate tools for removing laser covers				



In this laboratory exercise, the student will identify the components of a HeNe laser and safely operate the laser in the laboratory.

A. Elements of a Helium-Neon Laser

1. Examine an unplugged HeNe laser: The case that contains the laser should be opened so that the interior components are visible to the student.
2. In Data Table 1, make a sketch of the various components of this laser. Label the sketch to indicate the four elements of the laser, and identify the following additional components:
 - a. Time delay.
 - b. Aperture.
 - c. Safety interlock connector.
 - d. Safety labels.
 - e. Indicator light.
 - f. Power switch.
3. List the manufacturer and model number of the laser examined.

B. Operating Procedures for Helium-Neon Lasers

The student should--

- a. Become familiar with the procedures given below for the operation of a low-power HeNe laser.
- b. Complete the helium-neon laser test on safety precautions and operating procedures. The test is located at the end of this module and will be administered by the instructor. Accuracy of 100% is required for a satisfactory grade.
- c. After satisfactorily completing the Safety Precautions and Operating Procedures Test, the student will perform the remaining procedures. The instructor will use the Helium-Neon Laser Operation Checklist (Data Table 2) to evaluate the student's

performance.

1. BLOCK BEAM PATH.

Ensure that the laser "on/off" switch is in the "off" position. Direct the laser toward a dull surface or place a nonspecular reflector (block of wood) in front of the laser, as indicated in Figure 18. Ensure that the laser is not directed toward any person, door, window, or specular reflector.

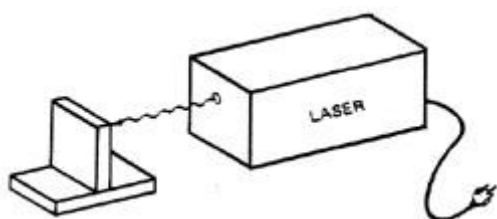


Fig. 18

Beam path block

2. PLUG IN THE LASER.

This laser must be plugged into the appropriate three-wire (grounded) electrical outlet (Figure 19).

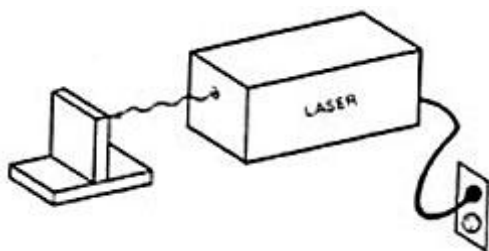


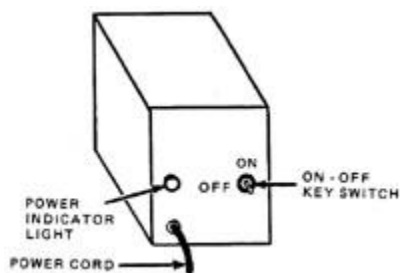
Fig. 19

Laser plugged in to **grounded** electrical outlet

The laser is operated with 110/120 volts, single-phase 50-60Hz ac power. The third-wire grounded terminal must not be bypassed.

3. TURN ON THE LASER.

Refer to Figure 20. The power switch is located on the same end of the laser as the power cord. Turn the laser "on."

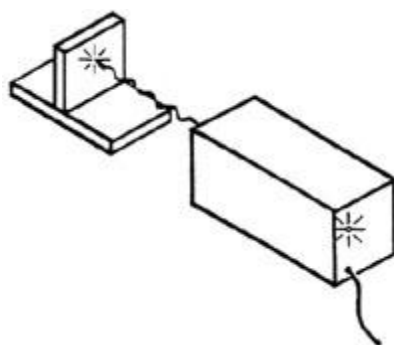
**Fig. 20**

Location of laser "on/off" switch and indicator light

The indicator light should come on immediately, followed by the laser beam in about 3 second.

4. VERIFY LASER OPERATION.

Check the dull surface or wood block and the pilot light to verify that the laser is operating. Refer to Figure 21.

**Fig. 21**

Verification of laser operation

5. CONDUCT OPERATING CHECK.

Allow the laser to operate a few minutes, observing whether the laser blinks off-and-on. If it blinks off-and-on, the laser tube probably has low gas pressure or a contaminated gas mixture and should be replaced.

6. TURN OFF THE LASER.

At the end of this experiment turn off the laser; unplug the cord; and leave the laser in a safe position. Remove the block of wood from the beam path.

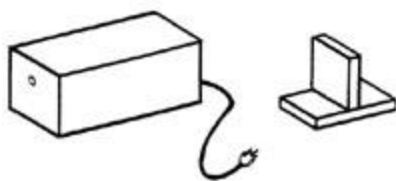


Fig. 22
Laser in "off" position



DATA TABLE 1

HeNe Laser Operating Checklist

U	S

The student will operate a low-power HeNe laser using safety precautions.

1. Enumerate all safety precautions.
2. List correct sequence operating procedures.
3. Operate low-power HeNe lasers.

- a. Block beam path.
- b. Plug in laser correctly.
- c. Turn on laser.
- d. Verify laser operation.
- e. Conduct operating check.
- f. Turn off laser.
- g. Observe safety precautions.



Note: In the revised version, we will include here, as we do in Module 3, *Intro to Laser Safety*, the current references for the American National Standard for Safe Use of Lasers. (We have currently listed ANSI 136.1 as that standard.)

Eleccion, Marce, "The Family of Lasers: A Survey," IEEE Spectrum, March, 1972.

Driscoll, Walter G., and Vaughn, William, eds. Handbook of Optics. New York: McGraw-Hill Book Company, 1978.

Lasers and Light - Readings from Scientific American. San Francisco: W. H. Freeman & Co., 1969.

Mallow, Alex, and Chabot, Leon. Laser Safety Handbook. New York: Van Nostrand Reinhold Company, 1978.

O'Shea, Donald; Callen, W. Russell; and Rhodes, William T. Introduction to Lasers and Their Applications. Reading, MA: Addison-Wesley Publishing Co., 1978.

Van Pelt, W.F.; Stewart, H.F.; Peterson, R.W.; et al. Laser Fundamentals and Experiments. Southwestern Radiological Health Laboratory, BRH/SWRHL 70-1, U.S. DEPT. OF HEALTH, EDUCATION AND WELFARE.

Verdeyen, Joseph T. Laser Electronics. Englewood Cliffs, NJ: Prentice-Hall. Inc., 1981.

Films

Laser Light. (Scientific American, 415 Madison Ave., New York, NY 10017.)



HeNe LASER SAFETY PRECAUTIONS AND OPERATING PROCEDURES TEST

List the HeNe safety precautions.

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.
- 7.

List the HeNe laser operating procedures.

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.

Name_____

