LASERS

LASER THEORY

Lasers are a very special source of light with some unique characteristics.

To understand principal of laser operation, consider three ways light can interact with the electrons in an atom.

The first of these is spontaneous emission in which the electron simply falls from the higher to the lower energy state, emitting a photon figure 1.

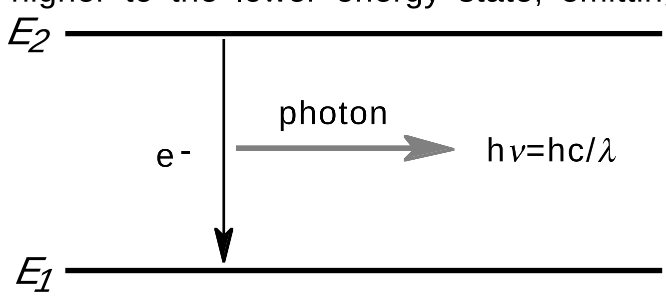

Figure 1. Spontaneous emission of a photon.

The second is absorption in which a photon "bumps" an electron from the lower to the higher level (figure 2). It goes best if the frequency and wavelength of the photon satisfy $h\nu = hc/\lambda \approx E_2 - E_1$.

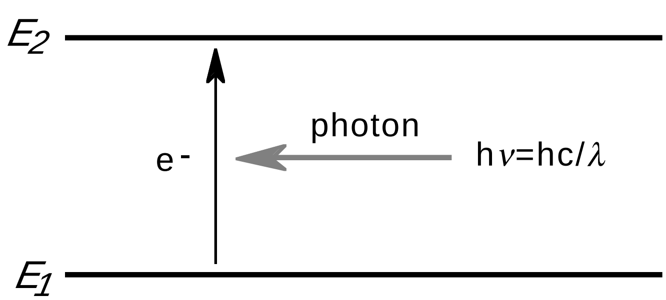

Figure 2. Absorption of a photon.

Finally, there is stimulated emission, in which one photon dislodges and electron which falls, emitting an additional photon. The two emitted photons are coherent.

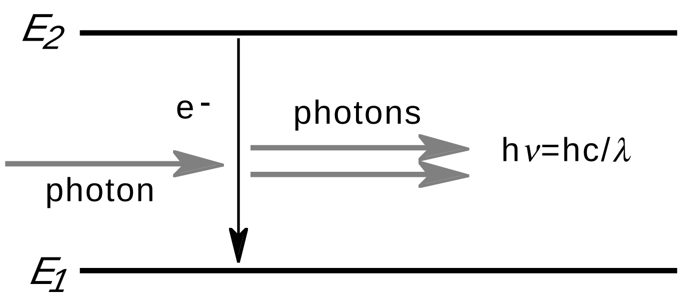

Figure 3. Stimulated emission

And stimulated emission compete. The winner depends on the relative population of states <1> and <2>. If there are more electrons in the upper state, absorption wins and if there are more electrons in the lower state, stimulated emission wins.

If there are more electrons in the upper energy level, we have <u>population inversion</u>. A medium with population inversion is an <u>active medium</u>. To produce an active medium we need energy input to the medium. This is called <u>optical pumping</u>.

In He-Ne lasers the pumping energy is supplied by a DC current through a gas mixture. Other kinds of pumping occurs in other kinds of lasers.

A He-Ne laser, like all lasers, needs a cavity, in this case two parallel mirrors.

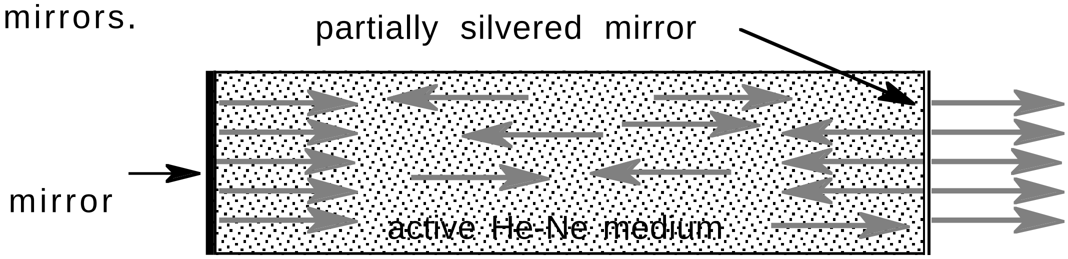

Figure 4. Construction of a He-Ne laser.

The laser action is produced by pumping He-Ne. Spontaneous emission kicks out some photons in random directions. Emission stimulated by these photons builds up, reflected back and forth between the mirrors gaining intensity and coherence until the beam leaks through the partially silvered mirror. The steady state is reached when light energy leaving the laser equals the pumping energy going into the laser.

Laser stands for the following acronym:

Light
Amplification by
Stimulated
Emission of
Radiation

APPLICATIONS OF LASERS

Laser light has several unique attributes which can be exploited in a variety of applications. These are:

- ☞ monochromaticity
- ☞ collimation
- ☞ intensity
- ☞ coherence

One thing lasers are *not* is efficient. A great deal of energy is lost in producing a laser beam.

HOLOGRAMS

A hologram reproduces the actual wavefront coming from an object, thus giving complete 3-dimensional information. A hologram is formed from the interference pattern caused by a reference beam and a beam reflected from an object. The wavefront from the object is reproduced by passing the beam from a laser through the hologram which acts as a sort of grating. Laser holography is possible because of the extremely long coherence length of laser light.

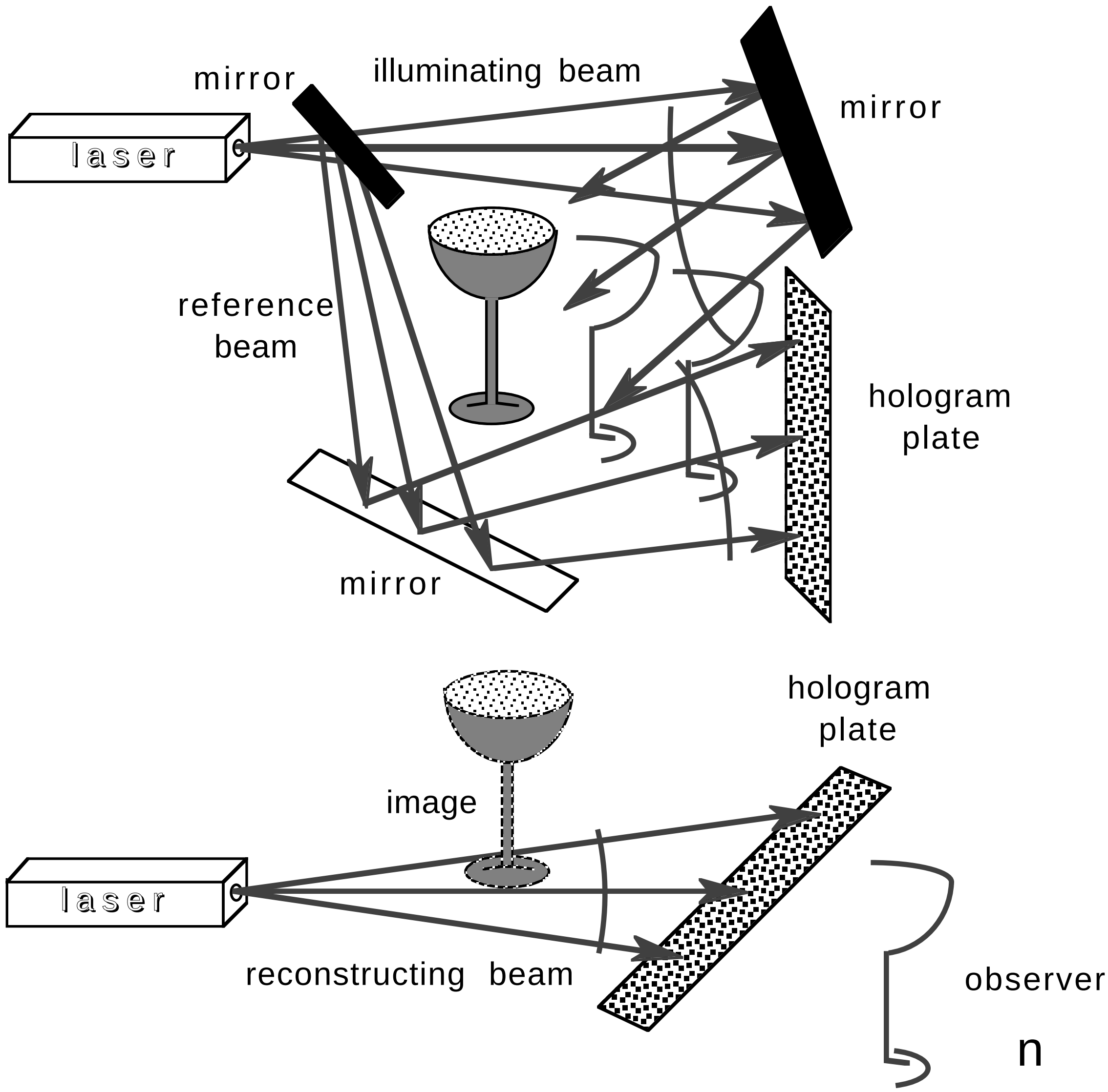

Figure 5. Producing a hologram (top) and viewing a hologram (bottom)

RETINAL FRINGES

Fringes may be formed right on the retina by coherent laser light as they are in Young's double slit interference. Usually these fringes can be formed even in the presence of a cataract. If the patient is able to distinguish a high frequency retinal fringe pattern, the chances are his retina is functional and the post surgical prognosis for vision after cataract extraction is good.

LASER EYE SURGERY

The high intensity of the laser beam means photocoagulation, trabeculotomy, capsulotomy, corneal sculpting, etc., can all be performed by aiming a laser at the offending structure.

LASER SPECKLE PATTERN REFRACTION

When a laser beam strikes a matte surface, an observer sees a characteristic speckle pattern. If the observer is an ametrope, he still sees the pattern sharply and clearly without his glasses. If he moves his head the pattern moves, the direction of the motion depending on his ametropia.

This phenomenon is often demonstrated by shining a laser beam on a rotating drum covered with matte reflector. The drum typically has the dimensions of a coffee can and rotates at very slowly, about one revolution per hour. Paper makes a pretty good matte reflecting surface. The configuration looks like the diagram below. The greater the ametropia, the faster the speckles seem to move.

A patient's refraction may be determined by placing lenses in front of the patient until the pattern stops moving. In the case of astigmatism, lenses are added until there is no net speckle motion in the direction of drum rotation. That determines the refractive error in the meridian perpendicular to the drum axis. Sphero-cylindrical refractive error may be deduced mathematically from refraction of three or more meridians.

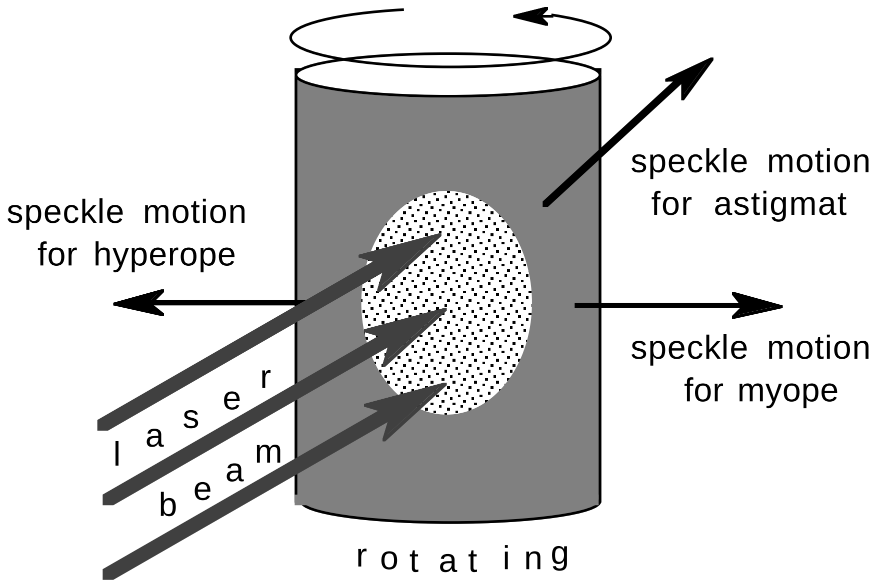

Figure 6. In laser speckle refraction, laser light aimed at a very slowly rotating matte surface produces a speckle pattern, the motion of which depends on the observer's ametropia.

But how can we explain the speckle pattern and its motion for myopes, hyperopes, and emmetropes? The pattern itself results from the fact that microscopically a matte surface has lots of small hills and valleys which become coherent secondary sources when a laser beam strikes them. The speckle pattern results from the interference pattern formed at the retina by these sources. (On the basis of this explanation, what would you expect to happen to the size of the speckles if the pattern were viewed through a pinhole?) Figure 7 shows the formation of the pattern on hyperopic, emmetropic, and myopic retinas.

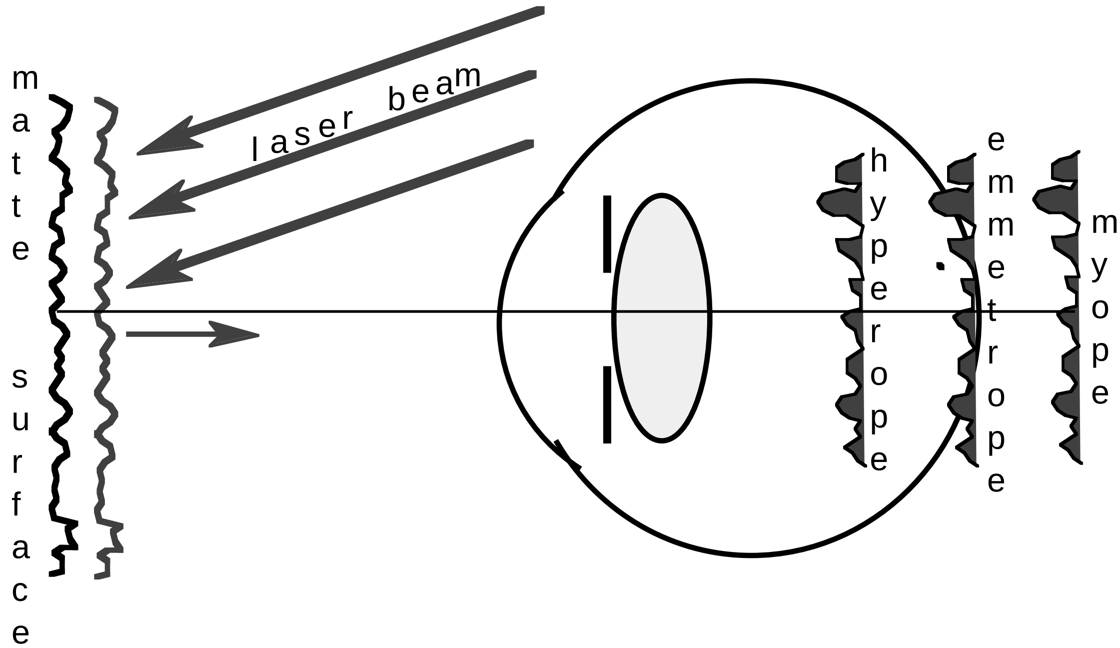

Figure 7. Formation of the laser retinal speckle pattern.

Now let the matte surface move upward some infinitesimal amount $dy \ll \lambda$. Because *dy* is so small, the pattern is unchanged on the emmetropic retina. As figure 8 shows, however, the pattern on the hyperopic retina moves upward on the retina relative to the pattern on the emmetropic retina and the pattern on the myopic retina moves down with respect to the pattern on the emmetropic retina. Referred back into space, this means the pattern moves with the motion of the drum for the myope and against the motion of the drum for the hyperope. The diagram also shows why the pattern moves faster for greater ametropias.

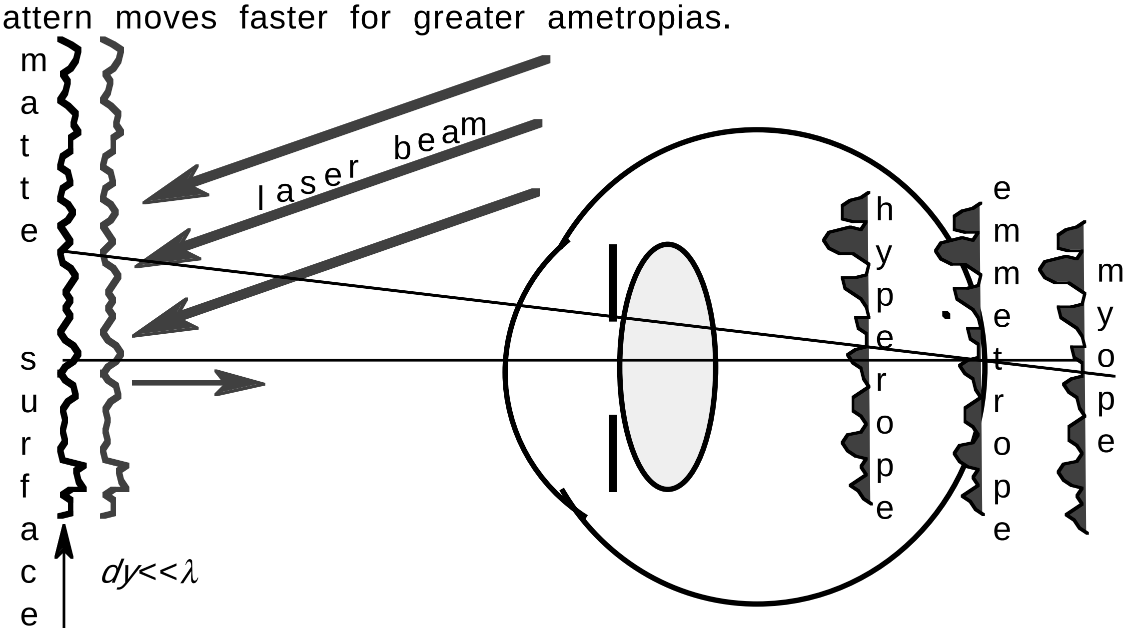

Figure 8. Movement of retinal speckle patterns in different ametropias.