University of Mosul
College of science
Department of Physics
Third Stage
Lecture 10

Laser

2024-2025

Lecture 10: The Pumping

Preparation
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10/11/2024

Laser Pumping Requirement

Excitation or Pumping Threshold Requirements

Excitation processes can in general be defined as: *any amount of population that is pumped into level u will decay within the lifetime associated with that level*. Thus, the pumping process to sufficiently fill level u effectively starts over for each lifetime duration τ_u of the level (it does not matter to be radiative or not). So, in general the rate equation of level u (which gave as)

$$\frac{dN_u}{dt} = N_o\Gamma_{ou} - N_u(\gamma_{ul} + \gamma_{uo}) = 0 \qquad \text{…………………125}$$

can be moified and used to indicate the significance of this concept. The steady-state solution for N_u is:

$$N_u = \frac{N_j\Gamma_{ju}}{\gamma_u} = N_j\Gamma_{ju}\tau_u$$

In this equation, N_j is the density in the state j of the species from which the energy is to be transferred (ground state o), Γ_{ju} is the pumping rate to the upper laser level u, from which we have $\tau_u=1/\gamma_u$, (where γ_{ul+} γ_{uo} was replaced by its equivalent γ_u). Because the population density N_u is directly proportional to τ_u, it can be seen that the longer the lifetime τ_u of the level, the more population will build up in that level.

If we express the exponential gain factor as $\sigma_{ul}(N_u\text{-}N_l)L$, we know that the portion of that factor leading to gain is the product $\sigma_{ul}N_uL$, whereas the factor - $\sigma_{ul}N_lL$ is detrimental to producing gain. Thus, to determine the *minimum pumping* flux required, we will deal only with N_u of course, more pumping flux would be required if N_l become significant compared to N_u. we can therefore express the minimum pumping flux Γ_{ju} as:

$$\sigma_{ul}N_uL = \sigma_{ul}N_j\Gamma_{ju}\tau_uL = \frac{1}{2}\ln\left(\frac{1}{R_1R_2}\right) \quad \text{with two mirrors.}$$

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Which gives the ***threshold value*** of the amplifier gain necessary to make a laser.

The third term in (126) is the pumping rate Γ_{ju}, which has units of 1/second. Γ_{ju} can be provided by:

[1]electromagnetic waves or light (optical pumping), *Optical pumping* can be provided either by lamps or other incoherent source or by lasers (coherent sources), and it is generally used for solid-state and dye laser.

[2]by particles such as electrons (particle pumping), *Particle pumping* is generally accomplished with electrons and is primarily confined to gaseous or plasma and also semiconductor lasers.

Pumping pathways

Two types of excitation pathways can be used to produce pumping of the upper laser level, direct pumping and in direct pumping.

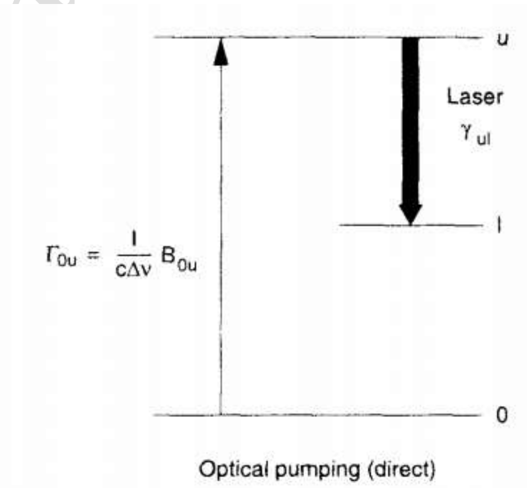
1) Excitation by Direct Pumping

In the direct pumping process, the excitation flux is sent directly to the upper laser level *u* from a source *j* in which the source state is the highly populated ground state o of the laser, as shown in Fig. (31). The pumping rate Γ_{ou} can be described in general terms for either optical pumping or particle pumping.

a) Optical Pumping

The excitation involves absorption of the pumping light within the gain medium, so we can write Γ_{ou} *as*:

$$\beta_{ul}(\nu)\Delta\nu u(\nu) = \beta_{ul}(\nu)I(\nu)\frac{\Delta\nu}{c} = \beta_{ul}(\nu)\frac{I}{c} \qquad \text{..................127}$$



Figure(31): optical pumping rate associated with direct pumping

The **optical pumping intensity** is the *intensity I that is within the absorption linewidth Δυ of the absorption species*. This can be converted to an energy density within the medium by replacing I/c by the energy density $u(\upsilon)$.

b) Particle Pumping

For gas lasers, Γ_{ou} can be written as

$$\Gamma_{ou} = N_p k_{ou} \qquad \text{..……………..128}$$

Where N_p is the pumping particle density (equivalent to the intensity factor in eq, (127) for optical pumping) and k_{ou} is the reaction probability for causing a transition from level o to level u when a particle p collides with the laser species in level o, has a **dimensions of volume per time.** This probability k_{ou} is often broken down into the more useful factors σ_{ou}, the cross section or probability for the transfer of energy from level o to level u and υ_{po}, the average relative velocity between the colliding species p and the target species o. The relation between these terms can be expressed as

$$k_{ou} = \bar{\upsilon}_{po}\sigma_{ou}$$

Thus, the population flux rate into level u from level o can be expressed as

$$\Gamma_{ou}N_o = N_p\bar{\upsilon}_{po}\sigma_{ou}N_o \qquad \text{……………..143}$$

Disadvantage of Direct Pumping

Direct pumping might seem to be a very straightforward and simple technique. However, many drawbacks are revealed when it is examined in more detail. These drawbacks are:

1. There may be no efficient direct route from the ground state o to the laser state u. For optical pumping, B_{ou} is too small to produce enough gain, for particle pumping, it would mean that the electron collisional excitation cross section σ_{ou} is too small.

2. There may be a good direct route from o to u, but there may also be a better route from o to l (the lower laser level) by the same process. In this case Γ_{ol}/Γ_{ou} may be too large to allow an inversion.

3. Even though there may be a good probability for excitation, there may not be a good source of pumping flux available. That is, there may not be insufficient

intensity I for optical pumping, or insufficient density N_p for particle pumping, at the specific energies necessary for pumping population from level o to level u.

Excitation by Indirect Pumping (Pump and Transfer)

Because of the restrictions on direct pumping outlined previously, multiple-step pumping processes-referred to here as *indirect pumping* or *pump and transfer*- have evolved over the years. These processes provide alternate routes to obtaining sufficient population inversion ΔN_{ul} for laser action. Indirect pumping processes all involve an intermediate level q and can be considered in three general categories as diagramed in Fig. (32): *transfer from below*, *transfer across*, and *transfer from above.*

For all three cases, the flux transfer rate from a level q to the upper laser level u can be written as

$$N_p \bar{\upsilon}_p \sigma_{qu} N_q \qquad \text{.................144}$$

for particle transfer, such as electrons, and as

$$\frac{I}{c.\Delta\upsilon} B_{qu} N_q \qquad \text{.................145}$$

for transfer by photon.

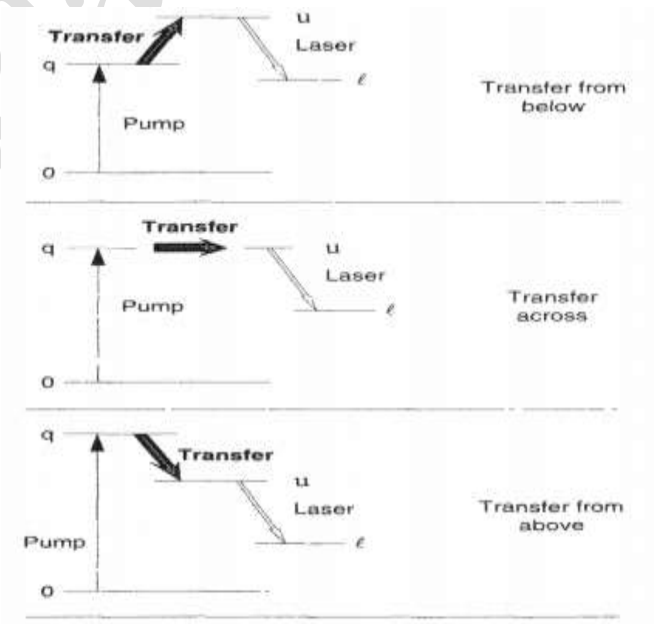


Figure (32): Three types of indirect pumping

Advantages of Indirect Pumping

There are a number of general comments that can be made about the advantages of such pump –and – transfer schemes. They all involve an intermediate level *q* that recives the pumping flux before it arrives at the upper laser level. In some cases populating the intermediate level *q* is a multiple-step process, but in most cases it involves only a single step. In any event, *level q is always much more closely located in energy to the upper laser level u* than is the initial level o. This makes the transfer of energy from level *q* to the upper laser level *u* a much easier task than pumping directly from level o to level *u*. This intermediate level *q* is used in different ways to overcome some of the possible problems outlined previously for direct pumping.

1. In some cases, the intermediate level *q* has a lifetime τ_q that is much longer than the lifetime τ_u of level u ($\tau_q >> \tau_u$). Level *q* might therefore accumulate more population than level *u*. Thus, for the case in which the pumping rate to level *q* and *u* are equal ($\Gamma_{oq} = \Gamma_{ou}$), N_q will still be much larger than N_u if $\tau_q >> \tau_u$. Hence level *q* can serve as a reserviour of population that is energetically near level *u*, with the possibility of transfer from *q* to *u* being much simpler than direct transfer from o to *u*.

2. In some cases the pumping probabilty (cross section) for pumping from level o to level *q* is much greater than that from o to *u*. This can significantly lower the pumping requirements.

3. *Transfer from q to u can be quite selective* in many cases, which implies that it occurs much more favorably to the upper laser level than to the lower laser level. This can often happen in a situation where direct pumping from o to *u* would *not be selective* or might even *detrimental* to the generation of an inversion.

4. Level *q* can belong to a different species of material than that associated with level *u*. This could allow the use of a material that can be efficiently excited to a storage level *q*. The stored energy is then transferred over to the laser level , either by a collisional or a radiative process, from one species to another. In this case the transfer process usually involves a collision of the species in the excited level *q* with the laser species in its ground state. The energy is then exchange from level *q* in one species to level *u* in the laser species, and level *q* reverts to its own ground state. One of the most common

processes of this type is the excitation and storage of energy in helium metastable levels (via an electrical discharge), which is then transferred to the neon laser levels to produce the well-known helium-neon laser, see Fig. (33).

5. Level *q* can have a very broad width and thus accept pumping flux of intensity *I* over a broad range of energies, in contrast with the upper laser level *u*, which might be quite narrow in order to provide a high stimulated emission cross section. This *q*-level capability is particulary advantageous for solid-state lasers in which the pump bands *q* are broad enough to collect the flux from a flashlamp having a broad spectral output.

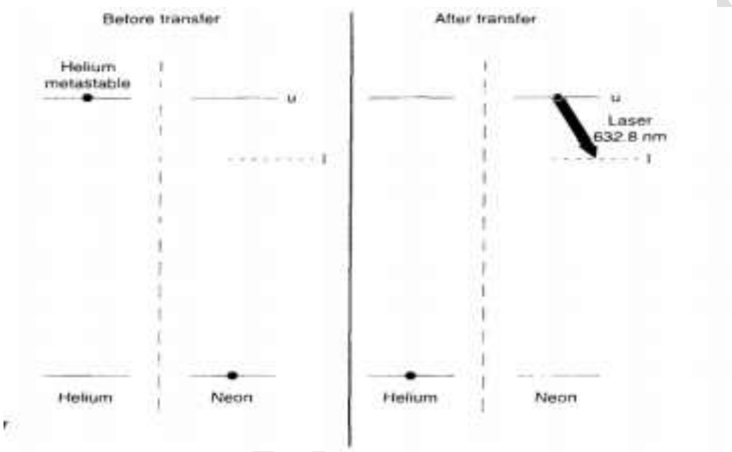


Figure (33): Collisional transfer of energy to upper laser level

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