PH 201

OPTICS & LASERS

Lecture_Lasers_9

Transient Population Inversions

Investigate possibility of transient inversion in a three-level system, where upper level is *u* & intermediate level is lower laser level *l*.

Allow pumping to both upper & lower laser levels from level 0.

Under steady-state condition in both three- & four-level systems, rapid decay have been seen. For transient situation, consider there is no decay from lower laser level.

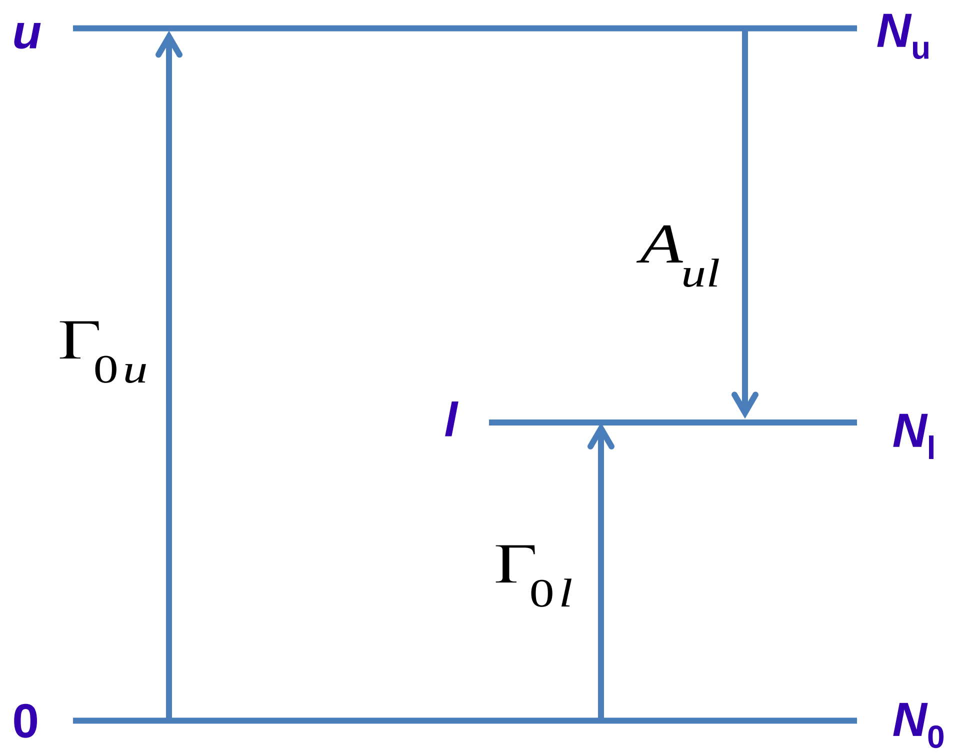
Though all levels above ground state eventually decay, we assume that decay from level *l* is so slow that it can be neglected for the time period under consideration (i.e., lifetime of upper laser level).

It is also assumed that there is no decay from level *u* to level 0. This decay is prevented by process *radiation trapping*. $\chi_{u0} = 0$

$$\tau_u = 1/\chi_u \cong 1/\chi_{ul} = 1/A_{ul}$$

There is no collisional decay.

Transient Population Inversions



Energy level diagram & relevant excitation & decay rates for a transient three-level laser system

Rate Eqs,

$$\frac{dN_u}{dt} = N_0 \Gamma_{0u} - N_u A_{ul}$$

$$\frac{dN_l}{dt} = N_0 \Gamma_{0l} + N_u A_{ul}$$

Since we are not considering steady-state conditions, we cannot equate these expressions to zero. Solutions for populations N_u & N_l are,

$$N_u = \frac{N_0 \Gamma_{0u}}{A_{ul}} (1 - e^{-A_{ul} t})$$

$$N_l = \frac{N_0 \Gamma_{0u}}{A_{ul}} \left[\left\{ \left(\frac{\Gamma_{0l}}{\Gamma_{0u}} \right) + 1 \right\} A_{ul} t - (1 - e^{-A_{ul} t}) \right]$$

$$N_u \rightarrow N_u = \frac{\Gamma_{0u}}{A_{ul}} N_0 \qquad when\ t >> \frac{1}{A_{ul}}$$

Steady-state solution

Since there is no decay from level *l*, N_l increases with time.

Considering necessary conditions to produce population inversion between levels *u* & *l*.

$$\frac{N_u}{N_l} = \frac{1-e^{-t/\tau_u}}{\left[\left(\frac{\Gamma_{0l}}{\Gamma_{0u}}\right)+1\right]\frac{t}{\tau_u}-(1-e^{-t/\tau_u})} > 1$$

Three situations are considered.

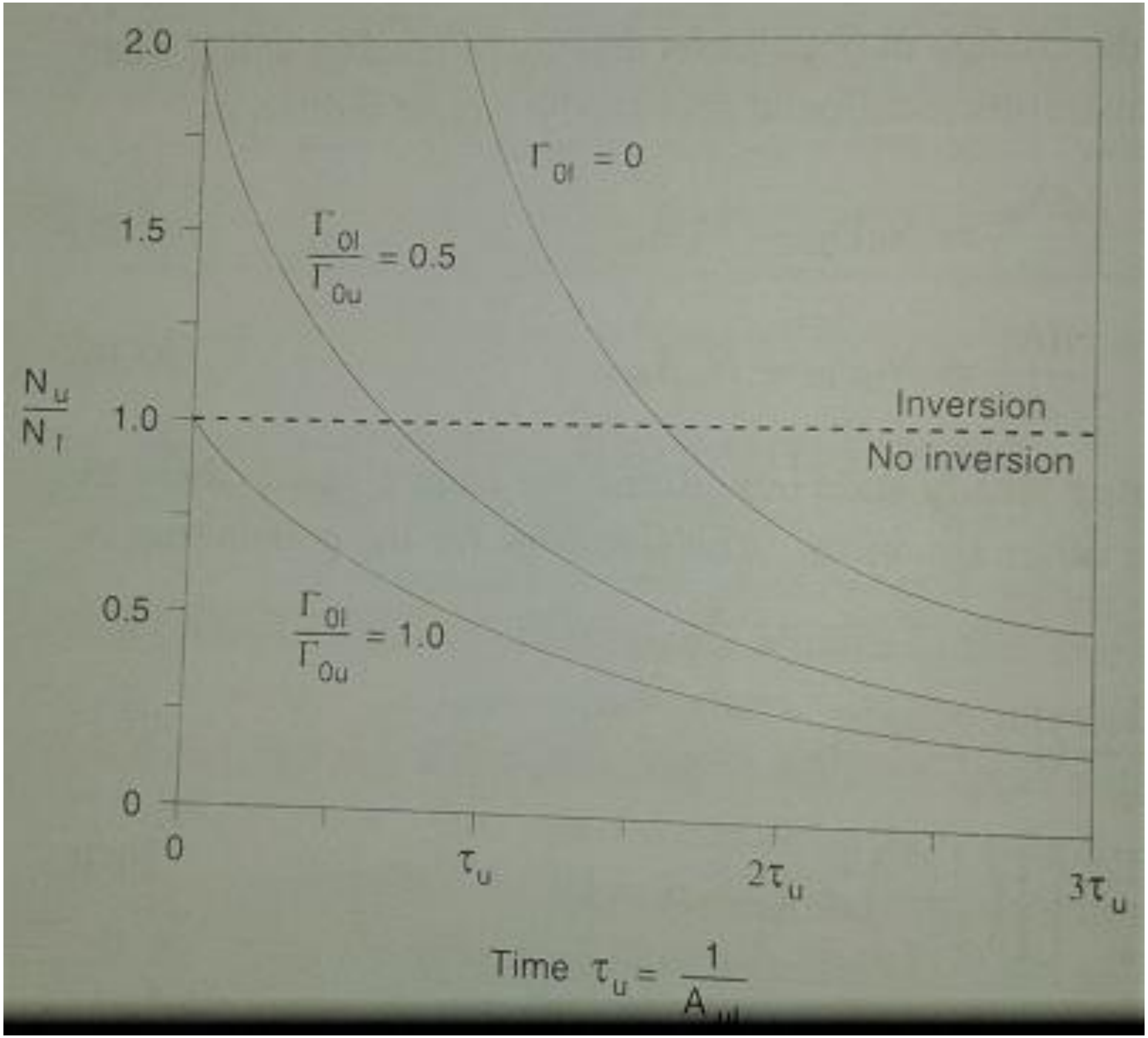
$$\Gamma_{ul} = 0$$

$$\Gamma_{0l} = \frac{\Gamma_{0u}}{2}$$

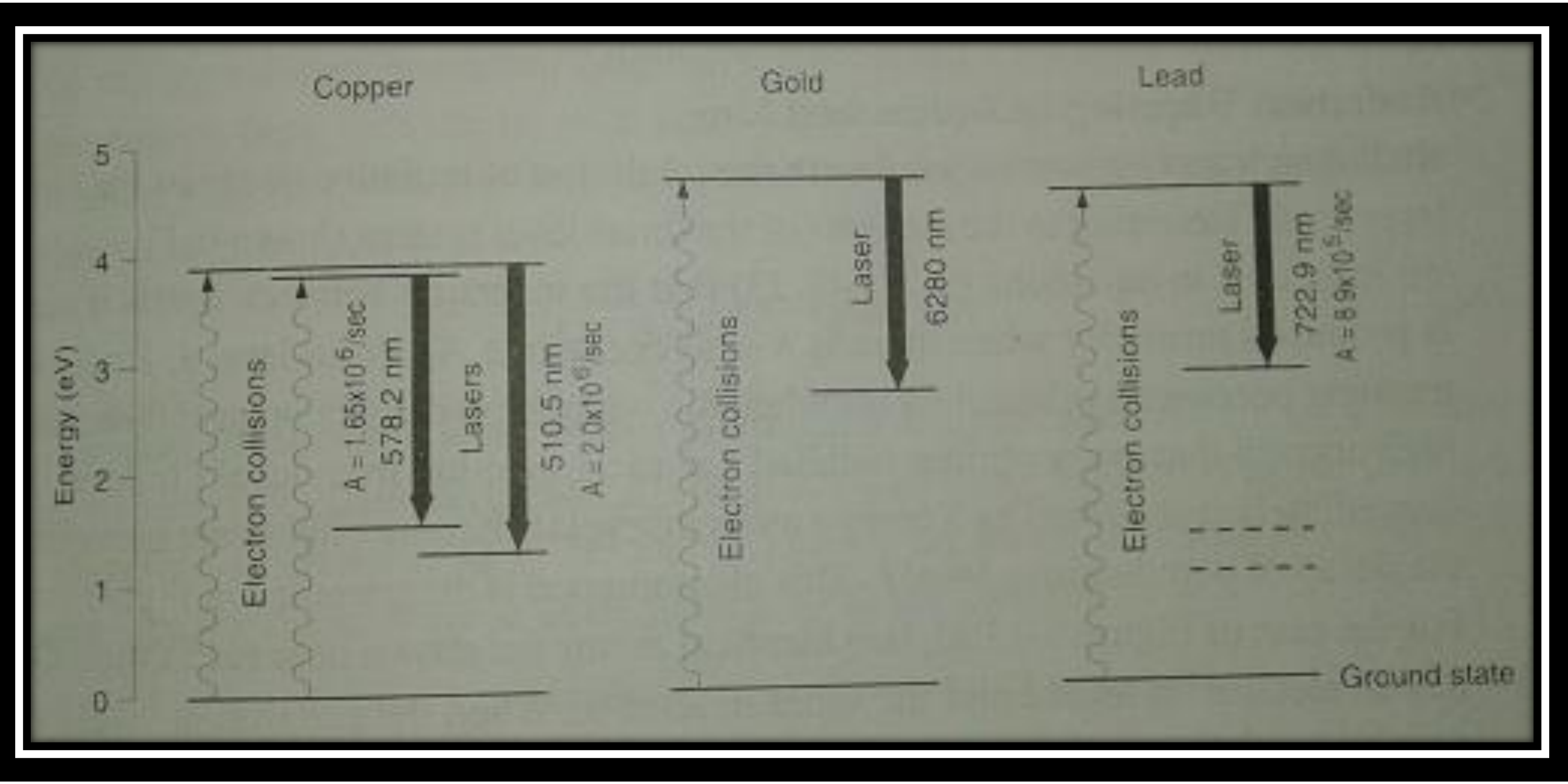
Inversion

$$\Gamma_{0l} = \Gamma_{0u}$$

No Inversion



Population density ratio N_u/N_l versus reduced time for a three-level transient inversion



Ex.: Transient three-level lasers

For copper vapor laser (CVL), gold vapor laser, & lead vapor laser; decay to other lower levels (other than lower laser level) such as to ground state or to two dashed levels in case of lead laser, is prevented by radiation trapping effects enabled by conditions under which these lasers operate.

There may appear to be other possible routes via which upper laser level can decay radiatively, but such processes do not occur: upper laser levels effectively decay only to lower laser levels.

CVL - there are two laser transitions.

Effective decay times for upper laser levels, ignoring decay to levels other than lower level, are reciprocal of radiative transition probabilities.

For 510.5 nm CVL transition,

$$\tau_u = 1/(2\times 10^6 s^{-1}) = 5\times 10^{-7} s$$

CVL- copper must be heated to a temp approx. 1500° C to adequately vaporize.

Processes that Destroy Inversions

There are three phenomena that can prevent population inversions from occurring.

1. **Radiation trapping** **(Gas lasers)**
2. **Electron collisional thermalization** **(Gas or plasma lasers)**
3. **Absorption within gain medium**

Radiation Trapping in Atoms & Ions

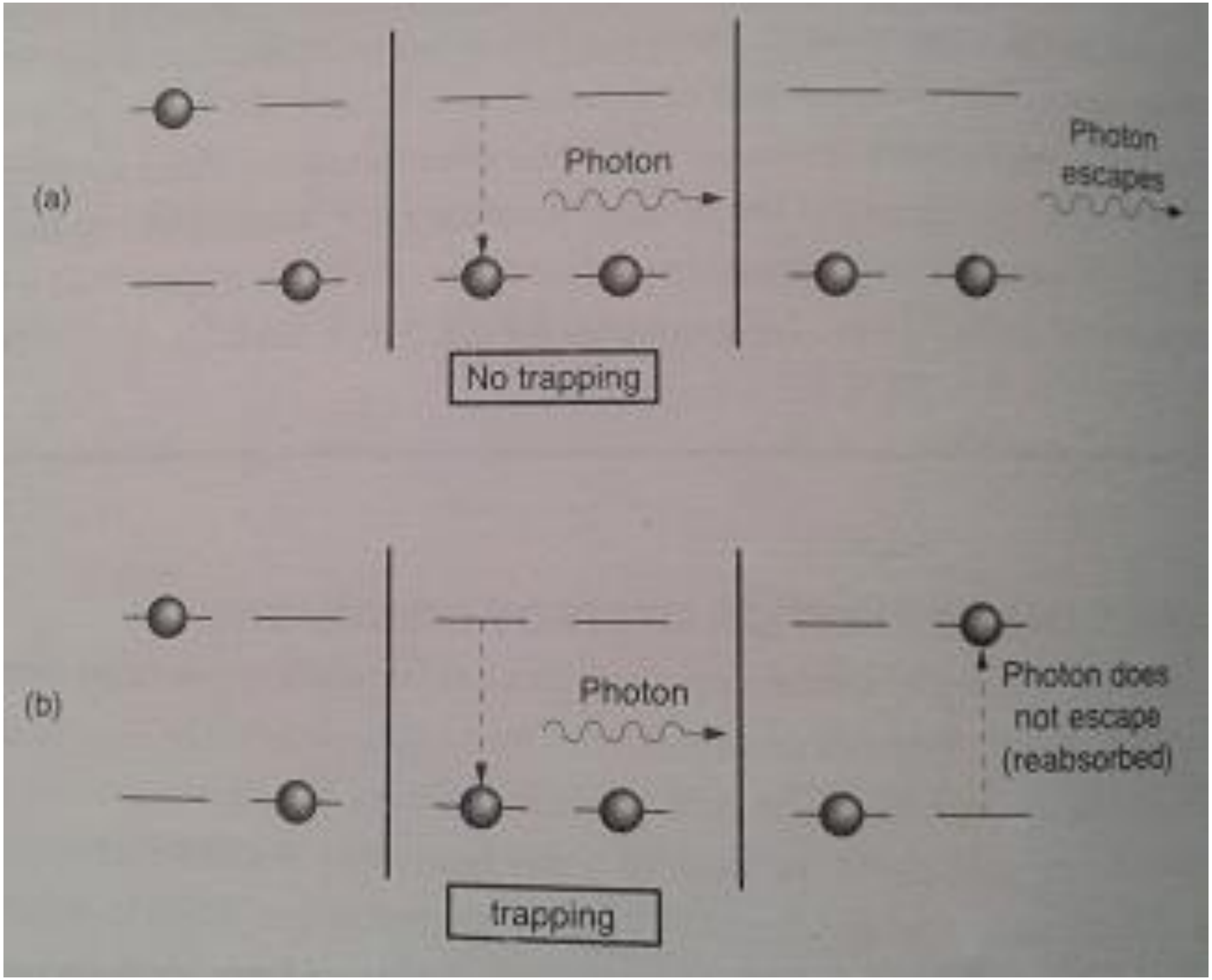
- **Radiative trapping prevents lower laser level from undergoing its normal decay process in a gas laser.**

- **Inversion between levels *u* & *l* is produced when there is a high decay rate A_{l0} from level *l*.**

- **Radiation trapping is relevant when population density in level 0 becomes high enough that every photon radiated due to transition from level *l* to 0 is immediately reabsorbed by a nearby atom in level 0, thereby preventing decay of population in level *l*.**

- **For most situations, in which radiation trapping is applicable,**

$$\frac{N_l}{N_0} << 1$$



Radiation trapping

Electron Collisional Thermalization of Laser Levels in Atoms & Ions

- In gaseous discharges or plasmas in which population inversions are produced, free electrons in discharge are the most common form of excitation of laser levels.

- Pumping electrons (discharge electrons) are referred to as free electrons, since they are not attached to atoms. These free electrons collide with atoms & excite them to higher energy levels.

- Presence of too many pumping electrons in laser gain medium is detrimental to making inversion, since electrons can also de-excite levels.

- Too many collisions between electrons & atoms within specific time period leads to thermalization of populations of upper & lower laser levels.

Absorption within Gain Medium

- In all lasers, absorption is inherent in specific gain medium & cannot be eliminated.
- Organic dye lasers have an overlap between absorption (pumping) spectrum & emission spectrum.
- When excimer lasers are pumped to upper laser level, it is possible to occur to higher excited molecular states.
- Many of transition metal solid-state lasers suffer from excited state absorption similar to excimer lasers.

Absorption in Semiconductor Lasers

- In semiconductor lasers, valence band is full or nearly full when no electric current is flowing in diode. For population inversion, a significant no. of holes must be created in that band.
- At any given energy within valence band, half of possible sites must be occupied by holes before there can be inversion. Below that no. of holes, there would be an absorption on a recombination transition that terminates at that energy.
- An extremely high current must be initiated to overcome initial absorption before gain exists.
- There is typically 0.2 m^{-1} of inherent absorption in a semiconductor laser, which must be overcome by current flowing in diode & adding holes within junction region.

Determine the single pass gain of a 0.1 m long Nd:YAG laser rod operating at 1.06 μm at room temperature. Assume the following:

(a) ***A*$_{ul}$ = 4 × 10^3 s^{-1}, no significant collisional or phonon broadening occurs on that transition, and there exist no radiative decay routes from level *u* other than to level *l*;**

(b) the pumping level *i* decays primarily to the upper laser level *u*, and the lower laser level *l* decays to the ground state 0, at a rate of 10^{12} s^{-1};

(c) the lower laser level i is 0.27 eV above the ground state;

(d) the pumping rate to the intermediate level *i* is 100 times the minimum value; and

(e) the doping concentration of the Nd:YAG rod is 10^{26} m^{-3}.