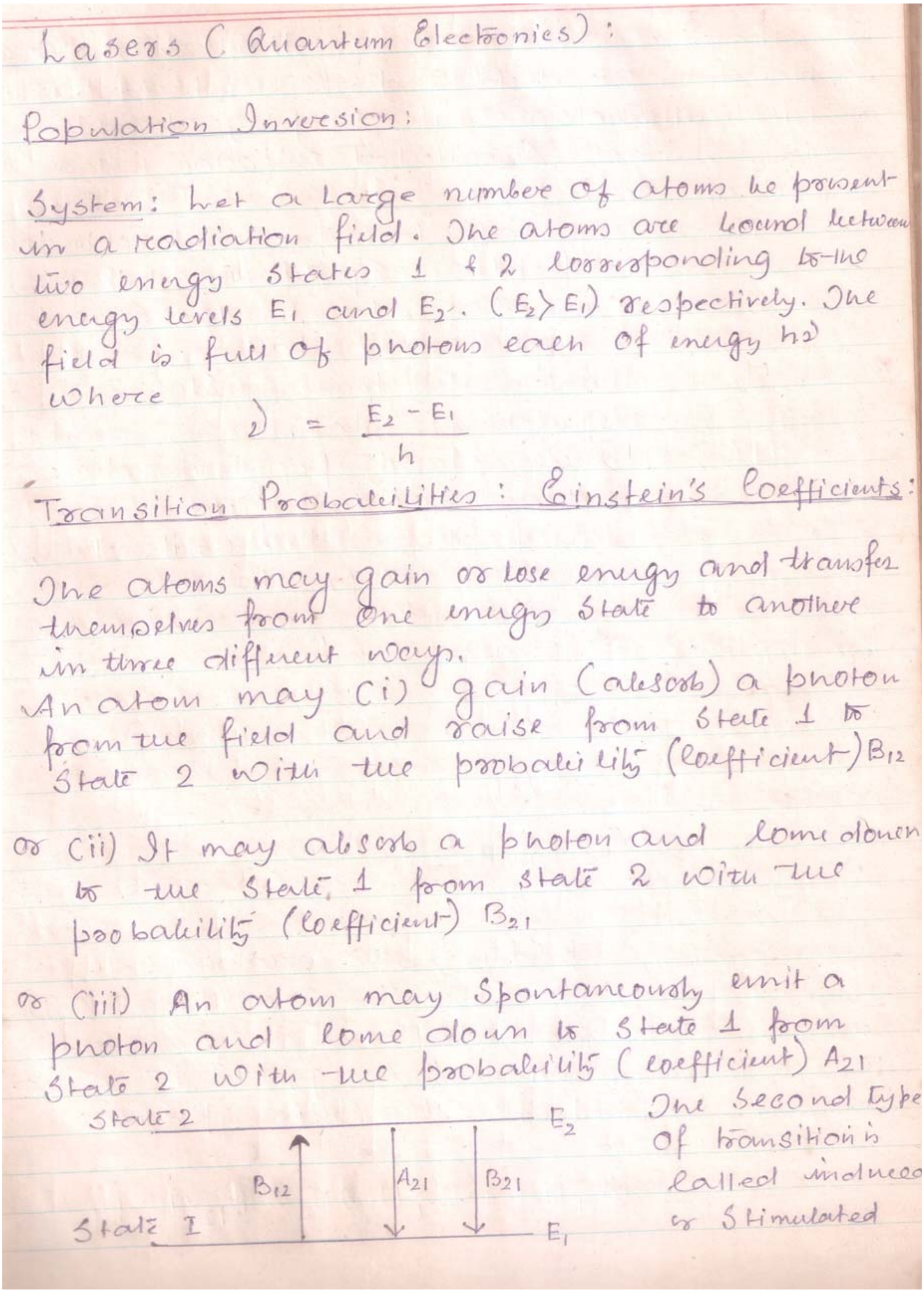


Lasers (Quantum Electronics):

Population Inversion:

System: Let a Large number of atoms be present in a radiation field. The atoms are bound between two energy states 1 & 2 corresponding to the energy levels E_1 and E_2. ($E_2 > E_1$) respectively. The field is full of photons each of energy $h\nu$ where

$$\nu = \frac{E_2 - E_1}{h}$$

Transition Probabilities: Einstein's Coefficients:

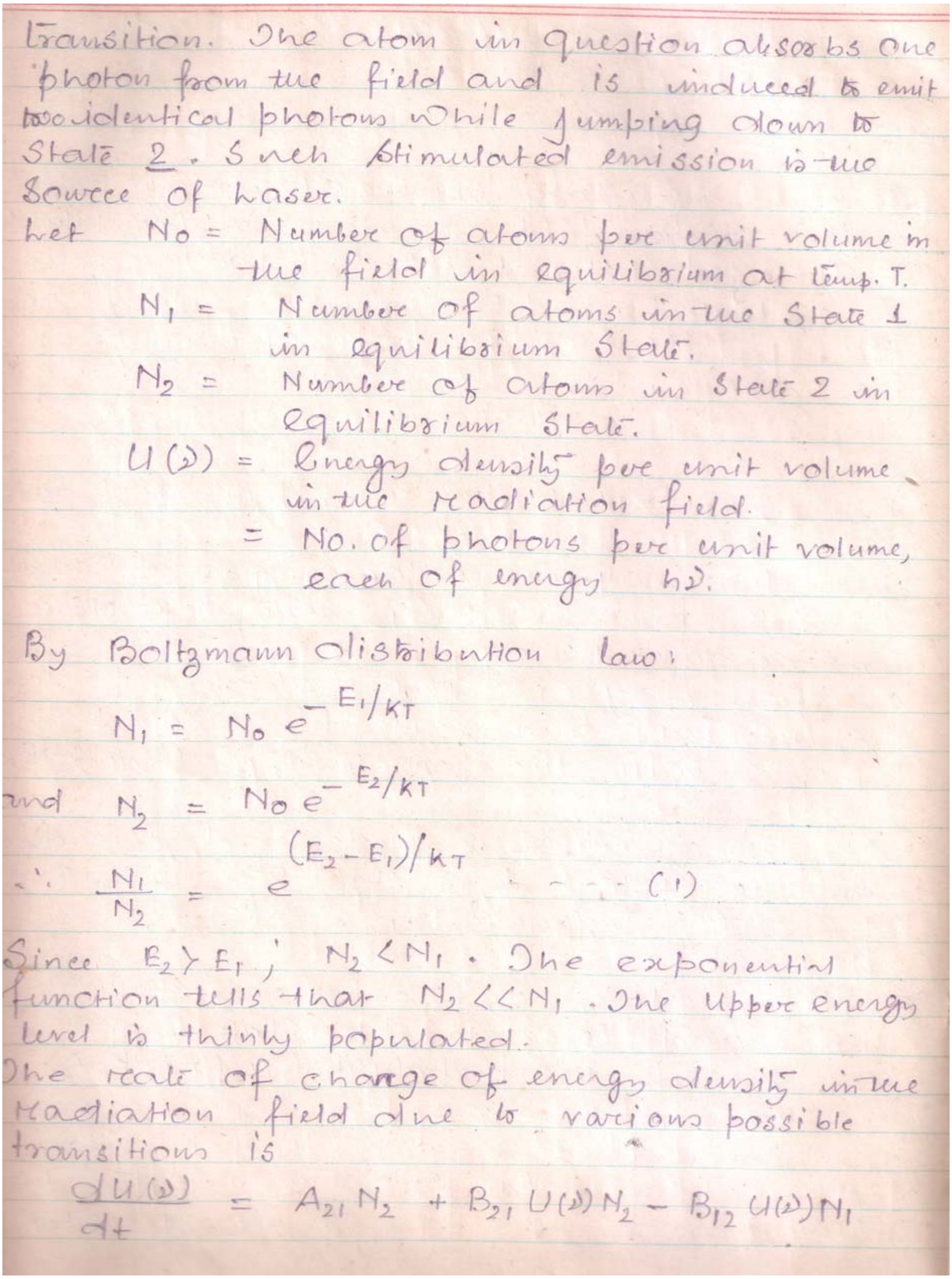
The atoms may gain or lose energy and transfer themselves from one energy state to another in three different ways.

An atom may (i) gain (absorb) a photon from the field and raise from state 1 to state 2 with the probability (coefficient) B_{12}

or (ii) It may absorb a photon and come down to the state 1 from state 2 with the probability (coefficient) B_{21}

or (iii) An atom may spontaneously emit a photon and come down to state 1 from state 2 with the probability (coefficient) A_{21}

The second type of transition is called induced or Stimulated



transition. The atom in question absorbs one photon from the field and is induced to emit two identical photons while jumping down to State 2. Such stimulated emission is the source of laser.

Let N_0 = Number of atoms per unit volume in the field in equilibrium at temp. T.

N_1 = Number of atoms in the State 1 in equilibrium State.

N_2 = Number of atoms in State 2 in equilibrium State.

$U(\nu)$ = Energy density per unit volume in the radiation field.

= No. of photons per unit volume, each of energy $h\nu$.

By Boltzmann distribution law:

$$N_1 = N_0 e^{-E_1/kT}$$

and $$N_2 = N_0 e^{-E_2/kT}$$

$$\therefore \frac{N_1}{N_2} = e^{(E_2-E_1)/kT} \quad \text{---}(1)$$

Since $E_2 > E_1$; $N_2 < N_1$. The exponential function tells that $N_2 << N_1$. The upper energy level is thinly populated.

The rate of change of energy density in the radiation field due to various possible transitions is

$$\frac{dU(\nu)}{dt} = A_{21} N_2 + B_{21} U(\nu) N_2 - B_{12} U(\nu) N_1$$

The System being in Equilibrium,

$\frac{dU(\nu)}{dt} = 0$. The principle of detailed balancing makes $B_{21} = B_{12}$

Hence, $$B_{21}\, U(\nu) \left(\frac{N_1}{N_2} - 1\right) = A_{21}$$

or $$U(\nu) = \frac{A_{21}/B_{21}}{\left(e^{h\nu/KT} - 1\right)} \quad \text{——} \; \textcircled{2}$$

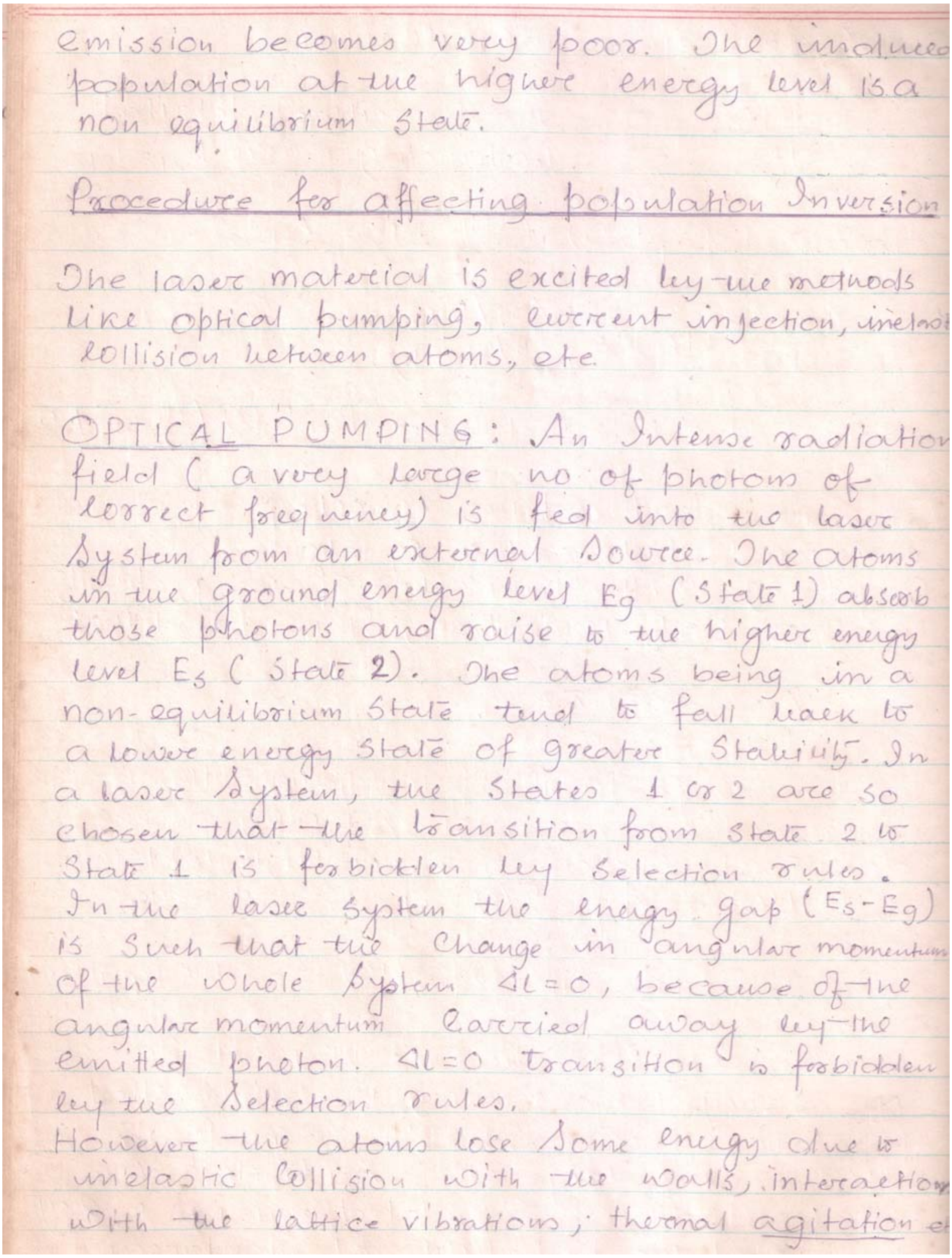
[Note : $N_1 \neq N_2$ and hence $B_{21}\, U(\nu) \left(\frac{N_1}{N_2} - 1\right) \neq 0$

Einstein introduced the concept of Spontaneous emission to balance the Equation]

Comparing with Plank's law of energy density in black body radiation, It is found that

$$\frac{A_{21}}{B_{21}} = \frac{8 h \pi \nu^3}{C^3}.$$

If the energy density of radiation $U(\nu)$ is increased to a very high value by raising density of photons to a very high level then as $U(\nu) \to \frac{\infty}{\textcircled{2}}$ $\left[e^{h\nu/KT} - 1\right] \to 0$. It makes $\frac{h\nu}{KT} \to 0$, $N_2 \to N_1$. If $U(\nu) \to \infty$ the equilibrium is lost making $N_2 \gg N_1$. The physical state of $N_2 \to$ very large making $N_1 \to 0$ is called population inversion. Also if energy density $U(\nu)$ is very large then A_{21} tends to zero. The probability of Stimulated emission is very high and the probability of Spontaneous



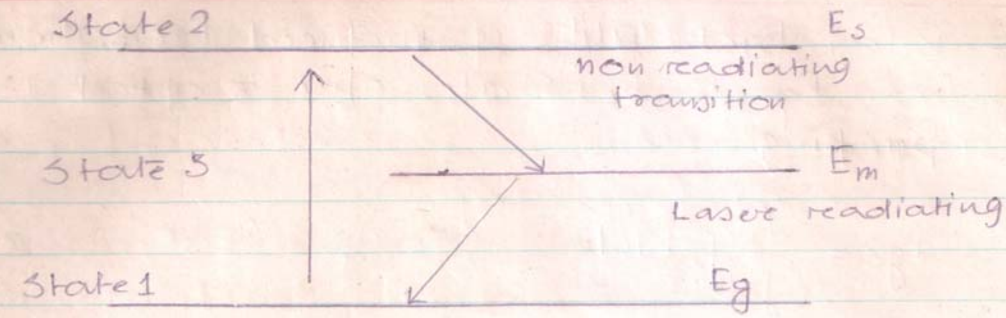
emission becomes very poor. The induced population at the higher energy level is a non equilibrium state.

Procedure for affecting population Inversion

The laser material is excited by the methods like optical pumping, current injection, inelast collision between atoms, etc.

OPTICAL PUMPING: An Intense radiation field (a very large no of photons of correct frequency) is fed into the laser system from an external source. The atoms in the ground energy level E_g (State 1) absorb those photons and raise to the higher energy level E_s (State 2). The atoms being in a non-equilibrium state tend to fall back to a lower energy state of greater stability. In a laser system, the states 1 or 2 are so chosen that the transition from state 2 to state 1 is forbidden by selection rules. In the laser system the energy gap $(E_s - E_g)$ is such that the change in angular momentum of the whole system $\Delta L = 0$, because of the angular momentum carried away by the emitted photon. $\Delta L = 0$ transition is forbidden by the selection rules.

However the atoms lose some energy due to inelastic collision with the walls, interactions with the lattice vibrations, thermal agitation et



The excited atoms relax into an intermediat energy level (State 3) called metastable state. The collection of the atoms in the meta-stable state is the population inversion. The band width ΔE in metastable state is narrow. The mean life τ in the excited state is in the order of 10^{-3} to 10^{-4} seconds. The mean life is large in compareision to the normal mean life of 10^{-8} secs. order. The atoms get a chance to built up in concentration.

$$\tau = \frac{3mc^2}{8\pi^3 e^2 \nu^2} = 1\cdot 6 \times 10^{-8} = \tau \text{ in normal excited state.}$$

The excited atoms jump down to the ground state emitting extremely coherent, intense photon shower. Normally, the emission would die out after a few bursts of readiation. The readiation is sustained over a prolonged period by the cavity resonance principle.