Introduction to Lasers (520.482)

Solution to HW4

Solve the following sets of Equations using Mathematica:

$$\frac{dn_2}{dt} = \frac{1}{\tau_2}(p - n_2 - n_2 n_p)$$

$$\frac{dn_p}{dt} = \frac{n_p}{\tau_p}(n_2 - 1) + \beta_{sp}\frac{n_2}{\tau_2}$$

Where $n_2 = N_2 / N_t$, $n_p = N_p / N_{p,sat}$, $p = R_p / R_{p,t}$ are the normalized parameters.

Plot everything in units of photon lifetime.

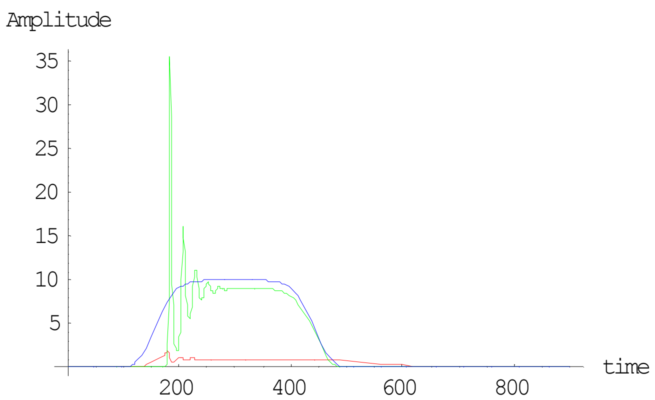
Pump pulse is Super-Gaussian: $p(t) = p_0 \exp\left(-\frac{t^6}{t_{pulse}^6}\right)$

<u>Conclusions from the graphs:</u>

(Blue: Pump function, Red: Population inversion, Green: Photon density)

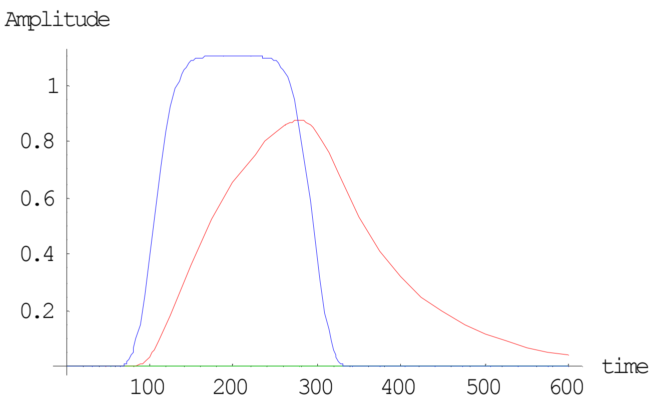
Graph 0: We see many oscillations here because the ratio τ_2 / τ_p is very large and the peak power is sufficiently high to reach the threshold value of population inversion.

0) $P0=10,\ t_{pulse}/\tau_2=\frac{3}{2},\ \tau_2/\tau_p=100$

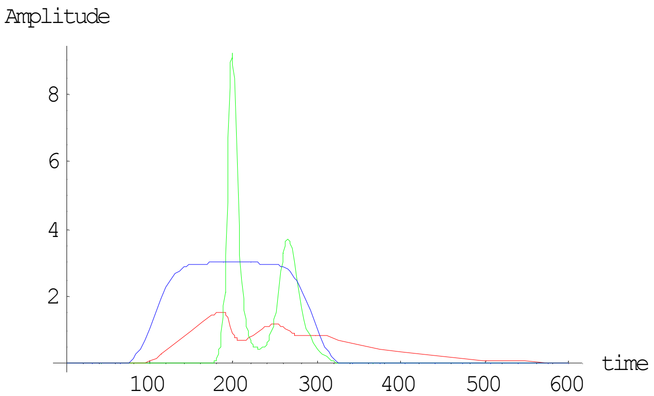


Graph 1-3: Oscillatory buildup of population inversion and the photon density can be seen as we increase the peak power.

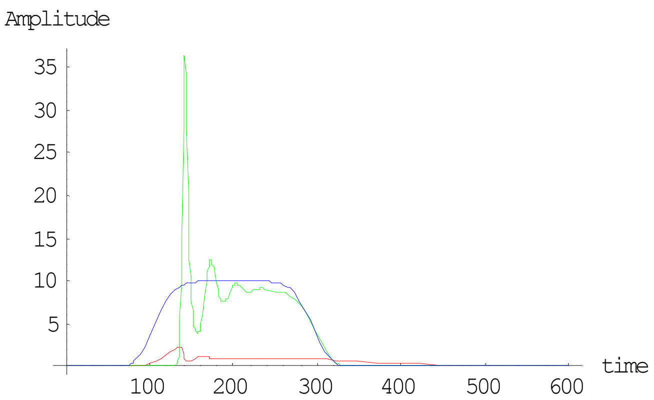
1) P0=1.1, t_{pulse}/τ_2=1, τ_2/τ_p=50



2) P0=3, t_{pulse}/τ_2=1, τ_2/τ_p=50

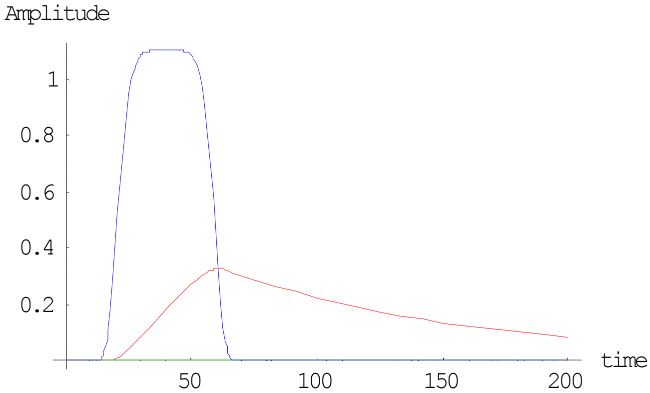


3) P0=10, t_{pulse}/τ_2=1, τ_2/τ_p=50

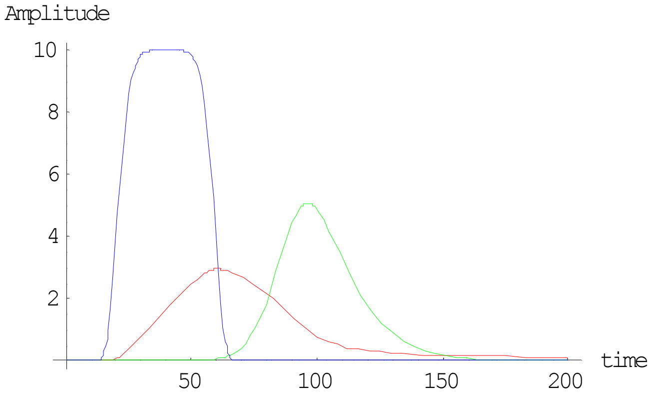


Graph 4-5: If we use a very short pulse, it provides very low energy to achieve sufficient population inversion (Graph4). And the oscillatory buildup is missing even at higher peak powers because the duration of the pump pulse is very small compared to the relaxation time.

4) $P0=1.1,\ t_{pulse}/\tau_2=\frac{1}{5},\ \tau_2/\tau_p=10$

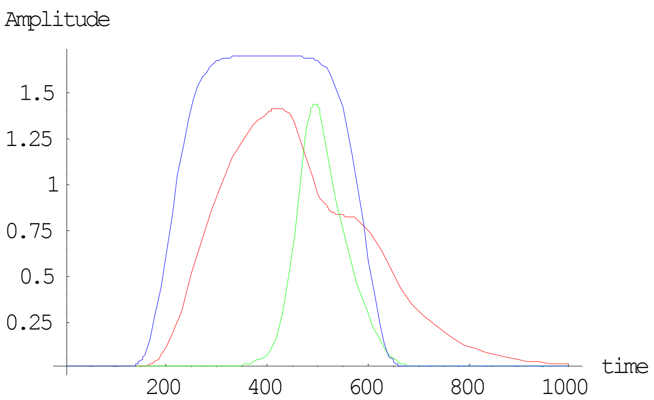


5) $P0=10,\ t_{pulse}/\tau_2=\frac{1}{5},\ \tau_2/\tau_p=10$

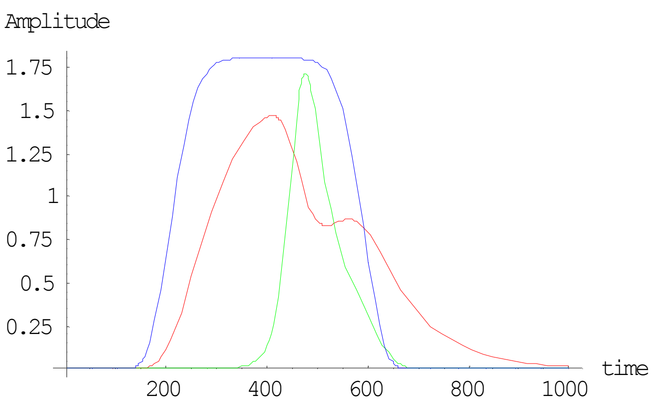


Graph 6-7 : If we use a long duration pulse, sufficient population inversion is achieved even at lower peak powers.

6) P0=1.7, t_{pulse}/τ_2=2, τ_2/τ_p=10

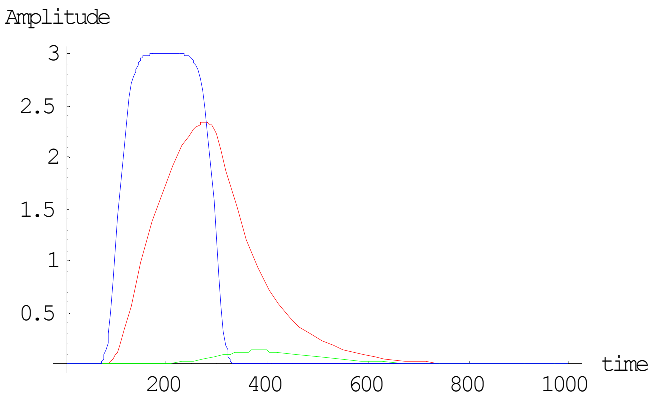


7) P0=1.8, t_{pulse}/τ_2=2, τ_2/τ_p=10

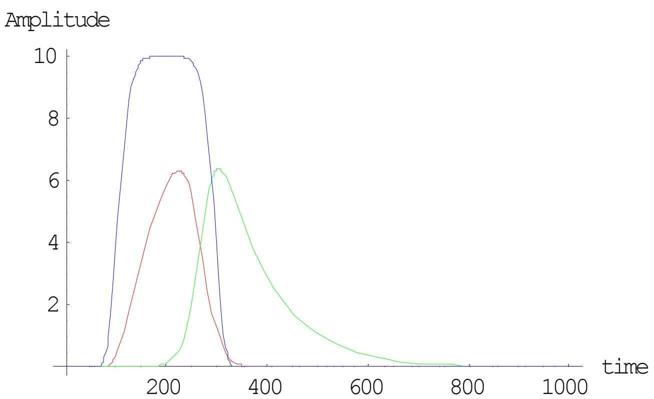


Graphs 8-10 : the photon life time is of the same order of relaxation time, which imply that τ_2 is very small. So you need to have higher peak power to get threshold value.

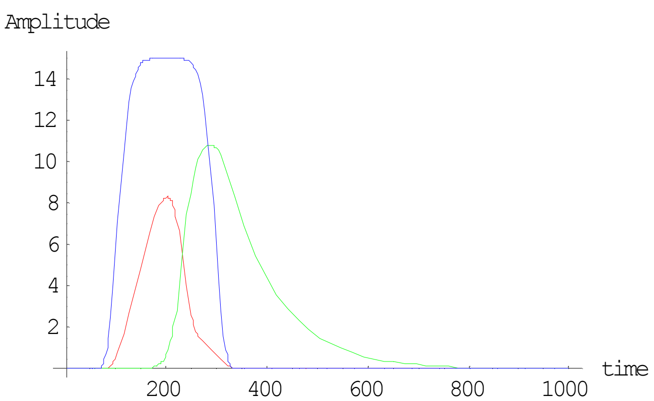
8) $P0=3,\ t_{pulse}/\tau_2=1,\ \tau_2/\tau_p=1$



9) $P0=10,\ t_{pulse}/\tau_2=1,\ \tau_2/\tau_p=1$

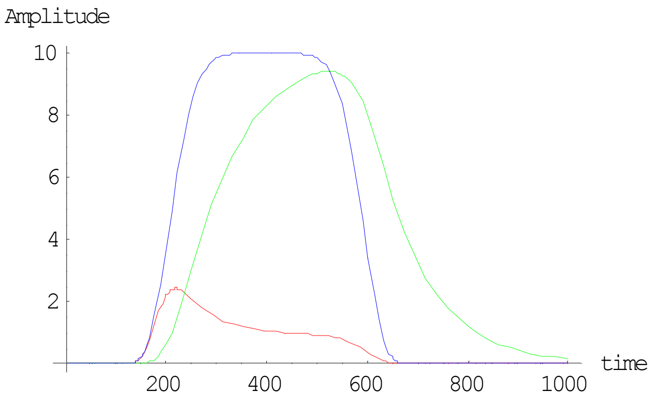


10) $P0=15,\ t_{pulse}/\tau_2=1,\ \tau_2/\tau_p=1$



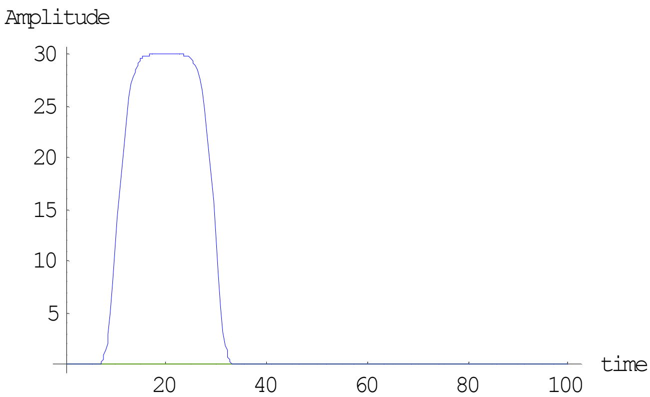
Graph 11 : If we increase the pump pulse length at high peak power, photon density will almost follow the pump power.

11) $P0=10,\ t_{pulse}/\tau_2=200,\ \tau_2/\tau_p=\frac{1}{100}$



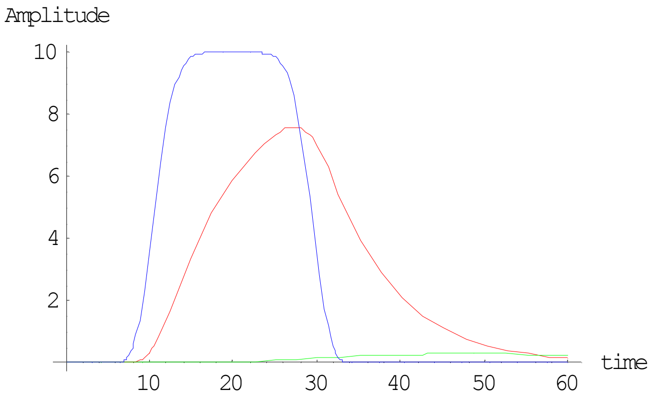
Graph 12: Again very short pulses are incapable of achieving threshold population inversion needed for lasing.

12) $P0=30,\ t_{pulse}/\tau_2=\frac{1}{10},\ \tau_2/\tau_p=1$

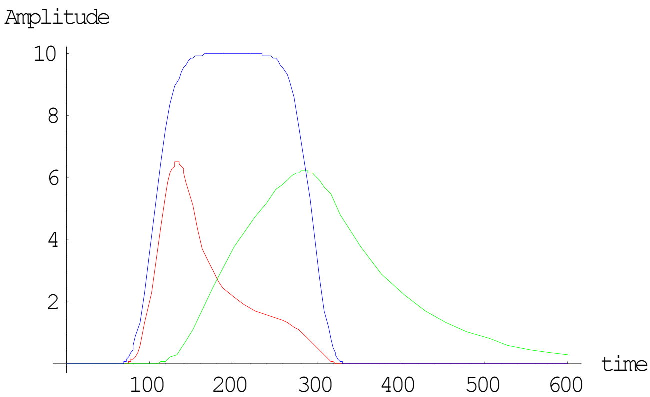


Graph 13-14: Since we are using normalized parameters, one of the way to look at it could be that it implies that the τ_2 is extremely small. Hence it is actually bad for laser. So you can only see it if you have very high pumping power for quite a long duration (Graph 14).

13) $P0=10,\ t_{pulse}/\tau_2=1,\ \tau_2/\tau_p=\frac{1}{10}$



14) $P0=10,\ t_{pulse}/\tau_2=10,\ \tau_2/\tau_p=\frac{1}{10}$



Conclusions: for a good laser, τ_2 should be very large. We see many oscillations here because the ratio τ_2/τ_p is very large and the peak power is sufficiently high to reach the threshold value of population inversion. Very short pulses might not have enough energy to achieve population inversion and might need very high peak powers. Very large duration pump pulses will have less of oscillatory evolution of photon density because the buildup will be more gradual.

Reason for oscillatory buildup of Photon density: Population inversion density builds up as the pulse is launched. When the population inversion density crosses the threshold, photon density start building up. The increase in photon density results more stimulated emission and hence it pulls down the population inversion density. So the photon density builds up to maximum but the same time population inversion density starts decreasing. This results in decrease of stimulated radiation and population inversion density rises again. This phenomenon results in oscillatory nature of radiations.