PH 2601 Introduction to Laser PYP 2011-2012

Textbook used: *Photonics and Lasers* by Richard Quimby. Some calculated answers are not included as usually the answer can be found simply by plugging in the given values into the expressions which the students should have obtained. That being said, most of the answers, if not all, can be found in the main textbook for this course. This solution functions generally as a pointer to the specific part of the textbook which contains the answer for the specific question. If you do not have the textbook, well, I must say that the textbook is rather important for this course, but I believe the lecture notes also contain bits from the textbooks, although some of the qualitative explanation may not be there .

1

a) This part may contain some bits which are not covered in lecture and requires some general knowledge on laser.

   i) Yes, it is true that laser has high energy output and thus it can be utilized to cut materials

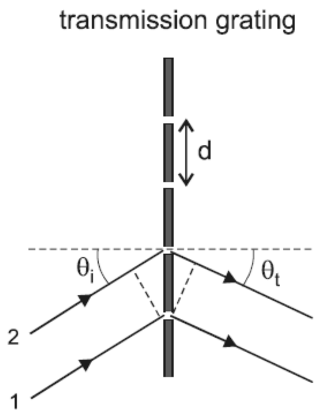
   ii) Yes, refer to Chapter 15, page 284 for more explanation on this

   iii) False. Excimer laser is used for laser surgery, but because it can cut without much residual damage to the surroundings (of the cut).

   iv) False. Photon energy is defined from its frequency, and most lasers do have similar frequency to "normal" light, but they do have much higher intensity, which may lead to it being used as a weapon.

b)

   i) (The illustration below can also be found from the textbook on page 21)



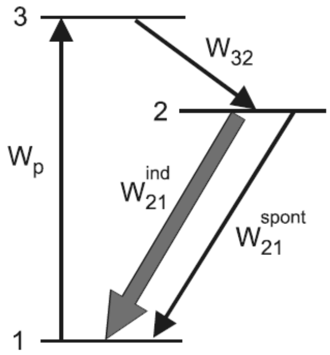
(*a*)

Line 1 and 2 above represents two different laser beams inside the cavity. Both will only contribute to the final output beam if the two beams interfere constructively. This can only be achieved if

$$d(\sin\theta_i + \sin\theta_t) = m\lambda$$

, where m is an integral. By adjusting the value of d, we can select individual discreet laser line.

ii) (Illustration from textbook page 352)



three-level system

In principle, 1 indicates the ground state of the atoms, 3 is the excited state and 2 is an upper state to which the atoms can decay quickly and non-radiatively. The transition from level 2 to level 1 results in spontaneous emission as well as the induced emission, which will result in the laser beam. The atoms are pumped from 1 using a high energy pump as to achieve population inversion in this model, at least half of the atoms must be on level 3 and much energy is required to achieve that state. Do note that this model is not very efficient compared to the four-level system as higher proportion of the ground level atoms need to be pumped up and hence the higher energy requirement. The first laser was based on three-level system though, and it was only able to operate on pulsed mode. Refer to page 351 of the textbook for more information.

2 (From Chapter 16)

a) For passive optical resonator, like what we have in this question (no gain medium used), the intensity after m complete round trips can be written as

$$I(t + \Delta t) = I(t){R_2}^m$$

The expression can be found in the textbook, page 298. R1=1 and thus is not explicitly stated in the expression above. Condition to achieve optical amplification: population inversion

b) $$\tau_c \approx \frac{2L}{c(1-R_1R_2)}$$

This is taken from equation 16-13 from the textbook; further explanation is also available there.

c) Cavity life time can be calculated very simply by plugging in the given values to the expression in part (b). FWHM, also written as $\Delta\nu_{1/2,}$ can be calculated using equation 16-17 from the textbook, that is

$$\Delta\nu_{1/2} = \frac{1}{2\pi}(1 - R1R2)(\frac{c}{n})/2L$$

Do note however, that I changed c in equation above to c/n (in equation 16-17, it is written as c, as in the derivation, it has been assumed that n=1 for simplicity, refer to page 298, last paragraph). Finesse can be easily calculated using equation 16-21, that is

$$F \cong \frac{2\pi}{1 - R1R2}$$

3 (Mostly from Chapter 20, with knowledge of chapter 18 required)

a) In equation 20-1 from the textbook, the threshold condition is defined as

$$R1R2e^{(\gamma-\alpha)2L} \geq 1$$

To solve forγ, we can take the natural logarithm of the expression above and we get

$$\gamma = \alpha + \frac{1}{2L}\ln(\frac{1}{R1R2})$$

This expression can be found in equation 20-2 of the textbook.

b) To obtain lasing, the gain coefficient γ must be larger than or equal to its threshold value. Utilizing the equation 18-35 and 18-36 of the textbook, the gain coefficient can be written as

$$\gamma = A_{21}\frac{\lambda^2}{8\pi}g(\nu)\Delta N$$

Solving for ΔN, and after considering the threshold condition, we can find the given expression in the question (also can be found as equation 20-4 of the textbook)

c) This part can be calculated simply by plugging in values to the equations from part a)

4 Chapter 22 (part a), Chapter 21 (part b)

a) Both mode locking and Q-switching are used to obtain short pulsed laser. The main difference between them is that for Q-switching, the laser makes fast transitions between non-lasing and lasing by switching its “Q state”. In mode locking, the laser runs continuously above the threshold level in several modes simultaneously; i.e. no switching between lasing and non-lasing. Self-focusing (See **Chapter 9**, page 147) in essence is “focusing” of the beam of light passing through a non-linear medium (different refractive index across its propagation direction). For application of Kerr lens in mode locking, refer to chapter 9, page 149. In short, only at sufficient intensity that self-focusing in the Kerr lens will occur. By self-focusing, the beam is “focused” or made less diverging, and hence more light is getting through the aperture. Figure 22-19 can shed extra light on this concept

b) Description of spectral and spatial hole burning can be found in textbook chapter 21, page 380-385. Physical cause for spectral hole burning: crystal imperfection (solid), Doppler shift (gas). Physical cause for spatial hole burning: different location (of atoms) of spatial regions of the mode pattern (different atoms at different spatial region will be saturated by different laser mode). To avoid confusion/ misunderstanding, I urge you to read from the text book directly.

c) Chapter 22 page 398, on discussion about electrooptic shutter. More discussion can be found also in chapter 9. In essence, pockels cell can re-align the polarization of the incoming light when a voltage is applied to it. Hence the output light can then be blocked by using an appropriate filter (polarizer) afterwards. In the context of Q-switching, when there is no applied voltage on the cell, the incoming light can be transmitted just fine, and the Q-state of that cavity is high. When the voltage is applied, the polarization of the light gets re-orientated and by using an appropriate end-filter, the output light will be minimized and this correspond to low Q-state of the cavity. Hence it is evident that by applying/not-applying the voltage, the pockels cell act as a switch for Q-switching process.