



**NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY**

**FACULTY OF APPLIED SCIENCES**

**DEPARTMENT OF APPLIED PHYSICS**

**BACHELOR OF SCIENCE HONOURS IN APPLIED PHYSICS PART IV**

**LASERS AND THEIR APPLICATIONS**

**SPH4202**

**Second Semester Examination Paper**

**March 2025**

This examination paper consists of 4 pages

**Time Allowed:** 3 hours  
**Total Marks:** 100  
**Special Requirements:** None  
**Examiner's Name:** Dr P. Baricholo

**INSTRUCTIONS**

**ANSWER ALL PARTS OF QUESTION 1 IN SECTION A AND ANY THREE QUESTIONS FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS.**

**MARK ALLOCATION**

QUESTION	MARKS
1.	40
2.	20
3.	20
4.	20
5.	20
<b>Maximum possible mark</b>	<b>100</b>

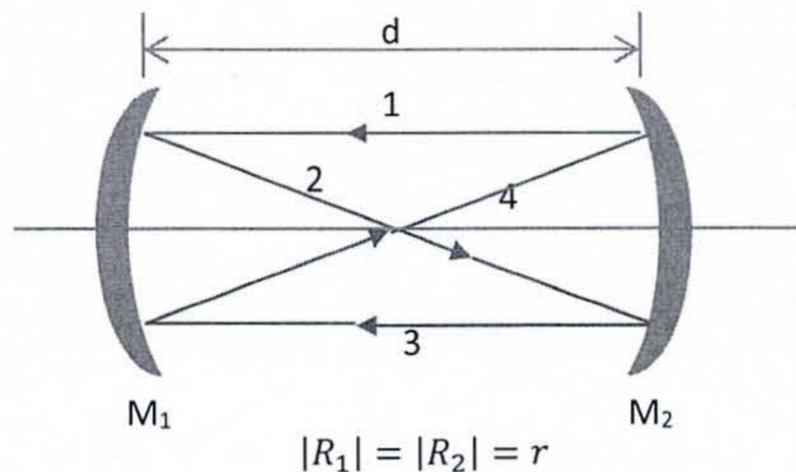
Planck's Constant  $h = 6.63 \times 10^{-34} \text{ J s}$   
Permittivity of Free Space  $\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$   
Permeability of Free space  $\mu_0 = 4 \pi \times 10^{-7} \text{ W m}^{-1}$   
Avogadro's Number  $N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$   
Boltzmann's Constant  $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$   
Rest mass of an Electron  $m = 9.1 \times 10^{-31} \text{ kg}$   
Charge on an Electron  $e = 1.6 \times 10^{-19} \text{ C}$

## SECTION A

1. a) i. Evaluate the ratio  $\frac{N_2}{N_1}$  for an optical transition,  $\lambda = 500 \text{ nm}$ , at room temperature, 300 K. [3]
- ii. A certain commercial helium-neon laser is advertised to have a far field beam divergence angle of 1 milli-radian at  $\lambda = 632.8 \text{ nm}$ . What is the beam spot size,  $\omega_o$ ? [3]
- iii. The power of the laser in ii. Is 5 mW. What is the peak electric field at  $r = z = 0$ ? [3]
- iv. How many photons per second are emitted in this laser beam? [2]
- b) Calculate the ratio of the stimulated emission rate to the spontaneous emission rate for an incandescent lamp operating at a temperature of 1000 K. It may be assumed that the average operating wavelength is  $0.5 \mu\text{m}$ . [4]
- c) Show that for the symmetrical resonator,  $0 \leq g_1 g_2 \leq 1$  yields the condition  $2r > L$ , where  $L$  is the cavity length and  $r$  is the radius of curvature of either mirror. [4]
- e) A He-Ne laser has the following specifications:  $R_1, R_2 = 1 \text{ m}$  and  $L = 0.5 \text{ m}$ . It is operated in a single  $\text{TEM}_{00}$  mode.
  - i. Calculate the minimum beam radius  $\omega_o$  and [2]
  - ii. the beam radius at a distance 10 m away from the minimum. [3]
  - iii. Draw a diagram showing the variation of the cross-section of the intensity profile. [3]
- f) Suggest some of the applications of diode lasers. [5]
- g) An  $\text{Ar}^+$  laser operating at 514.5 nm has a laser cavity constructed with a pair of mirrors having a 2 m radius of curvature, separated by a distance of 1.8 m. Determine if the cavity is stable. [4]
- h) Highlight the differences, if any, between solid state lasers and semiconductor lasers. [4]

## SECTION B

2. a) A neodymium-doped glass laser is constructed by doping a phosphate glass rod of length 10 cm with  $\text{Nd}^{3+}$  ions, and placing mirrors at each end of the fiber. The mirror reflectivities are 1 for the end reflector, 0.95 for the output coupler and the attenuation coefficient in the rod is  $0.2 \text{ m}^{-1}$ . The lasing transition has a center wavelength of 1054 nm, a spectral width of 19 nm, and an oscillator strength of  $7.5 \times 10^{-6}$ . Determine the population inversion needed for lasing in this system. [5]
- b) What is the effective blackbody temperature of the laser beam near the output mirror in a laser cavity? [5]
- c) i. Suggest where a diffraction grating could be used in laser development. [2]  
 ii. Explain why it is suitable for this application. [2]
- d) Show that  $\frac{\text{Rate of stimulated emission}}{\text{Rate of spontaneous emission}} = \frac{1}{e^{\frac{h\nu}{k_B T}} - 1}$ . All the terms have their usual meaning. [6]
3. a) Lasers have found a number of military applications. Suggest the types of lasers used by the military and give reasons as to why these specific lasers are used? [5]
- b) i. Suggest two types of lasers used for welding and give reasons as to why these specific lasers are used? [5]  
 ii. What kind of excitation is used with the fibre laser? [2]  
 iii. Why is this method not used with  $\text{N}_2$  lasers? [3]
- c) Show that the waist of the beam  $2\omega_0$  is fully determined only by the radius of curvature  $R$  of the mirrors, and is given by  $2\omega_0 = \left(\frac{2\lambda R}{\pi}\right)^{\frac{1}{2}}$ . [5]
4. a) Figure 1 below shows two identical concave spherical mirrors forming a confocal cavity.



**Figure 1**

Show, without first specifying the value of  $d$ , that after traversing the cavity two times the

system matrix is 
$$\begin{bmatrix} \left(\frac{2d}{r} - 1\right)^2 - \frac{2d}{r} & \left(\frac{d}{r} - 1\right)\frac{4}{r} \\ 2d\left(1 - \frac{d}{r}\right) & 1 - 2\frac{d}{r} \end{bmatrix}. \quad [8]$$

- b) Data are stored on compact discs by laser writing patterns of ‘pits’ and ‘lands’ along a continuous spiral path. What feature(s) of the laser would you consider modifying to enable greater amounts of data to be stored? [4]
- c) Identify each of the following broadening mechanisms as homogeneous or inhomogeneous. Explain your answer.
- Collisions between atoms in a gas. [2]
  - Randomly spaced impurities in a semiconductor crystal. [2]
  - Temperature differences between different regions of the gain medium. [2]
  - Vibrational relaxation within an energy band of an atom or semiconductor (this is the same thing as dissipation of electronic energy into phonons within an energy band). [2]
5. a) Give two examples for each of “wavelength splitting” and “amplitude splitting” interferometers. [4]
- b) i. Define power density at saturation in terms of photon energy, photon lifetime and total population. [3]
- ii. For a two level system, show that  $\frac{\Delta N}{N_T} = \frac{1}{1 + \frac{I}{I_s}}$ , where all the terms have their usual meaning. [4]
- c) Discuss at least three medical applications of lasers, identifying the type of laser and how it is used as well as suggesting why the particular laser is suited for the application. [9]
6. a) An  $\text{Ar}^+$  laser operating at 514.5 nm has a laser cavity constructed with a pair of mirrors having a 2 m radius of curvature, separated by a distance of 1.8 m. Determine if the cavity is stable. [5]
- b) Describe Q-switching highlighting why this technique is important in laser development. [5]
- c) Discuss how lasers can be used in the steel manufacturing industry, identifying the type of laser and how it is used as well as suggesting why the particular laser is suited for the application. [10]

*END OF EXAMINATION*