Q 1. A helium-neon laser emitting at 633 nm makes a spot with a radius equal to 100 mm at $1/e^2$ at a distance of 500 m from the laser. What is the radius of the beam at the waist (considering the waist and the laser are in the same plane)?

The problem can be solved by using the formula that links the divergence of the beam and the waist size:

$$\Theta = \lambda / \Pi \times w_0$$

So

$$w_0 = \lambda / \Pi \times \Theta$$

Θ is expressed in radians and is equal to 100×10^{-3} m/500m which is equal to 2×10^{-4}m

$$w_0 = (633 \times 10^{-9}\text{m}) / (3.14 \times 2 \times 10^{-4}\text{m})$$

$$w_0 = 1 \text{ mm}$$

Q2 Calculate the gap in frequency between two longitudinal modes in a linear cavity whose optic length, L =300 mm.

The gap between two consecutive longitudinal modes is defined by

$c/2L$; where $c = 3 \times 10^{8}\ ms^{-1}$.

$L = 0.3m$

The gap is therefore equal to 500 MHz.

Q 3 . What is the rate of repetition of the pulses emitted by a mode-locked laser? The optic length of the cavity, L, is 1 m.

The gap between two pulses from a mode-locked laser is defined by

$$2L/c.$$

The frequency is therefore equal to $1/(2L/c)$

$$= 150\text{MHz}$$

Q 4 . A mode-locked laser emits an average power P equal to 1 W. The rate of repetition of the pulses from this laser is equal to 100 MHz. Calculate the energy of each pulse.

The period between each pulse is equal to

τ = 1/ repetition rate

During this period, only one pulse is emitted.

The energy (E) is therefore found from

$$E=P\tau$$

$E = 1Js^{-1} / 10^8$ Hz

$= 10$ nJ

Q5. Consider a lower energy level situated 200 cm^{-1} from the ground state. There are no other energy levels nearby. Determine the fraction of the population found in this level compared to the ground state population at a temperature of 300 K.
Boltzmann's constant is equal to $1.38.10^{-23} JK^{-1}$
The conversion from cm^{-1} to joules is given by:
$E(J) = 100hc\, E(cm^{-1})$, where h is Planck's constant (6.62×10^{-34}Js) and c is the speed of light in a vacuum ($3 \times 10^{8} ms^{-1}$)

Boltzmann's Law is used:

$$N_2 = N_1 e^{-(E_2 - E_1)/kT)}$$

By considering the energy of the ground state to be zero and calling 0 the ground state and 1 the lower energy level:

$N_1 = N_0 e^{-(E_1)/kT)}$ After converting cm^{-1}->joules

$E_1 = 3.97 \times 10^{-21}$J ;

$E_1/kT = 0.96$

$N_1/N_0 = 0.38$

Q 6 . Consider an optical pump at 940 nm for a Yb:YAG crystal placed in a laser cavity. The wavelength of ytterbium is 1030 nm. If all the photons emitted by the pump are absorbed by the crystal and used for the lasing process, calculate the maximum power output. The pump power is 1 W.

At best, a pump photon gives a laser photon. The maximum output power is defined by

$$(P \times h\nu_l)/ h\nu_p$$

$\nu_{l,}$ ν_p are laser and pump frequency respectively

$$P \times \lambda_l / \lambda_p = 912 \text{ mW}$$

Q 7 .The amplifying medium of a helium-neon laser has an amplification spectral band equal to $\Delta\nu$ = 1GHz at 633 nm. For simplicity, the spectral profile is assumed to be rectangular. The linear cavity is 30 cm long. Calculate the number of longitudinal modes that can oscillate in this cavity.

The number of longitudinal modes is equal to the spectral band divided by the interval between the two longitudinal modes

$$N = \Delta\nu/(c/2L) = 2$$

Q 8 . A Q-switched laser emits pulses of 10µJ of duration 1 ns. The repetition rate of the pulses is equal to 10 kHz.

1. Calculate the peak power of the pulses.

2. Calculate the average output power of the laser.

1. The peak power is the energy of the pulse divided by its duration: = 10kW

2 . The average output power is determined by saying that for one period (T=1/10kHz), one pulse is emitted so = 100mw