LASER

Challenging **MCQ** questions by The Physics Cafe

Compiled and selected by The Physics Cafe

1 **(a)** Stimulated emission and spontaneous emission are two processes in which photon emissions can take place.

Explain the main difference between how these processes can happen.

[1]

(b) State and explain the importance of stimulated emission in the production of lasers.

[2]

(c) Explain what is meant by population inversion and why is it an essential condition in laser production.

[2]

(d) Fig 5(a) shows the energy level diagram of a **three-level laser**. Lasing takes place between E_2 and E_1 while Fig 5(b) shows the energy level diagram of a **four-level laser**. Lasing takes place between E_3 and E_2.

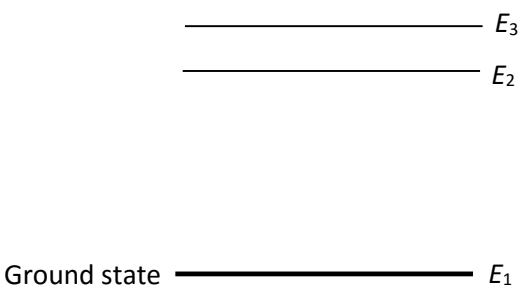

Fig 5(a)

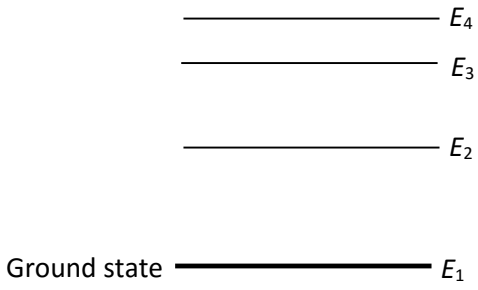

Fig 5(b)

State the advantage of the four-level laser over the three-level laser.

.....

.....

.....

.....

[2]

.....

Ans (a) Stimulated emission is <u>triggered by an external photon</u> whereas spontaneous emission happens <u>on its own accord</u>.

(b) In stimulated emission, a photon of energy equal to the energy difference between the metastable state and lower excited state will trigger the transition of the atom to the lower energy state.

This results in **2 emitted photons that have the same frequency and hence coherent.** In addition, the photons emitted are **in phase,** have the **same polarization and** are moving in the **same direction**

These photons further stimulate more photons that are in phase, creating a coherent beam of laser light of high intensity.

(c) Population inversion that is, there being more **excited atoms in the higher energy state than a lower one** is one of the conditions required
This ensures that **the probability that an incident photon will stimulated emission exceeds the probability that the photon will be absorbed** *as Incident photons can cause either stimulated absorption or stimulated emission.*

(*If there is no population inversion, incoming photons will be more likely absorbed to cause excitation rather than to result in stimulated emission as upper energy level is unoccupied. It is required so that the stimulated emission dominates spontaneous emission in the excited atoms*.)

(d) **The 4 level system ensures there is always population inversion between E_3 and E_2 as E_2 undergoes rapid spontaneous emission to E_1**

This <u>reduces the loss of photons by stimulated absorption</u> between the upper (E_3) and lower (E_2) laser level.

(*Note Level 4 is practically empty due to fast spontaneous emission, hence any appreciable population accumulating in level 3, the upper laser level, will form a population inversion with respect to level 2. That is, as long as population in level 3 > 0, then a population inversion is achieved between E_3 and E_2.*

Since only a few atoms must be excited into the upper laser level to form a population inversion, a four-level laser is much more efficient than a three-level one, and most practical lasers are of this type.)

2 A helium-neon laser tube consists of a 1:4 mixture of helium and neon gases, neon being the medium in which laser action occurs. Fig. 6.1 shows the few important energy levels involved in the actions.

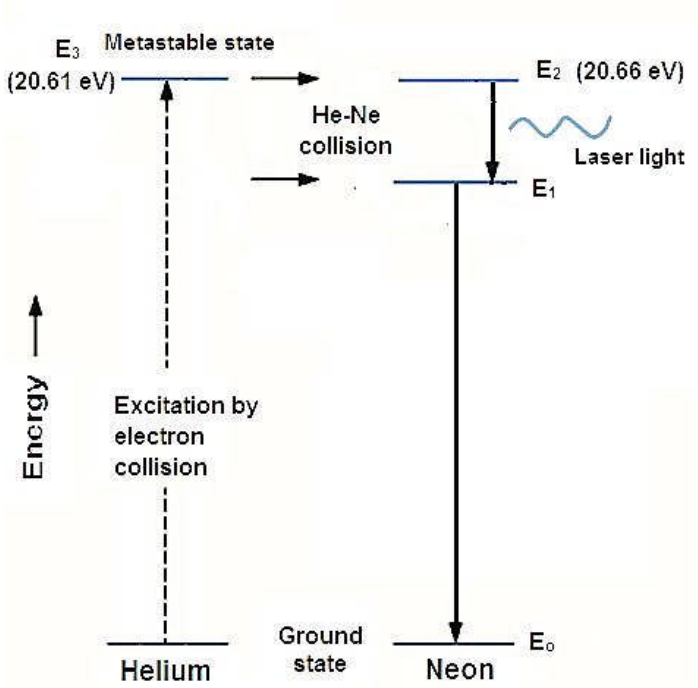

Fig. 6.1

Helium atoms are excited to a metastable state E_3 from ground state by collisions with high speed electrons. The energy in E_3 is then transferred to energy level E_2 by collisions between the helium and neon atoms. Laser light is then released when the electrons in E_2 state fall to E_1 state.

(a) Estimate the order of the time an electron will stay in the following states before falling to lower states

(i) metastable state E_3,

time = …… s

(ii) energy state E_2 or E_1.

time = …… s

[1]

(b) Electrons in E_3 have energy of 20.61 eV. This is not enough to raise the electrons from the ground state to E_2 which requires 20.66 eV. Suggest why this excitation is possible.

……..

…….. [1]

(c) Lasing occurs when electrons fall from E_2 state to E_1 state. Give a brief explanation of how population inversion is achieved between these two levels.

……..

……..

……..

…….. [2]

Ans (a) (i) 10^{-3} s

(ii) 10^{-8} s

(b) The atoms in the mixture possess kinetic energy. Neon atoms absorb kinetic energy during collisions with the helium atoms to make up the difference.

(c) Any excited electrons in E_2 and E_1 in Neon atoms will fall to the ground state in 10^{-8} s. E_3 is a metastable state which allows electrons to stay for 10^{-3}s. Many helium atoms in E_3 state falls to ground state together during collision and pass the energy to the neon atoms and excite them to the E_2. So E_2 state will have a higher population compared to the E_1 state, population inversion is thus achieved.

3 **(a)** Explain what is meant by the *metastable state*.

.....

[1]

.....

(b) Ruby is a crystal of aluminium oxide Al_2O_3 in which some aluminium ions are replaced by chromium ions. It contains 0.05% to 0.5% of chromium and its colour is pink. It is the energy levels of chromium, which takes part in lasing action to produce the distinct red colour laser light in the ruby laser.

The energy level diagram of chromium is shown in Fig 4.1 below.

(Note that the energy values in this diagram are relative to the ground state, E_1, which is taken to be 0 eV.)

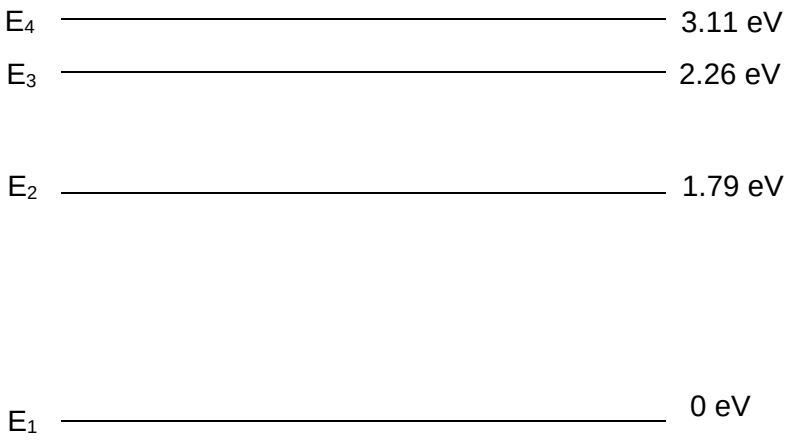

Fig. 4.1

(i) By showing suitable calculations, determine which energy level is the metastable state. Explain your reasoning clearly.

metastable state …… **[4]**

(ii) The ruby laser delivers a 10.0 ns pulse of 1.00 MW average power. Estimate how many photons are present within each pulse.

number of photons = …… **[2]**

Ans (a) It is defined as a **<u>higher energy level</u>** where **<u>electrons can stay for a much longer period of time</u>** than the usual 10^{-8}s.

(b) (i) As the laser light is red, a suitable **estimate** for the wavelength of red light is 700 nm.

Therefore, the energy transition involved should be about

$$\Delta E = \frac{hc}{\lambda_{red}} = \frac{(6.63\times10^{-34})(3.0\times10^{8})}{(700\times10^{-9})(1.6\times10^{-19})}$$
$$= 1.78 \text{ eV}$$

The most suitable state transition that corresponds with the above energy change is from E_2 to E_1.

Since **<u>laser light is produced via stimulated emissions from the metastable state</u>**, and that **<u>population inversion is needed for lasing action to occur</u>**, the energy transition has to occur starting from the metastable state to a lower energy state.

Therefore, the metastable state is **<u>E_2 (1.79 eV)</u>**.

(ii)
$$E_{pulse} = N_{photons} E_{photon}$$
$$N_{photons} = \frac{E_{pulse}}{E_{photon}} = \frac{P\Delta t}{\Delta E}$$
$$= \frac{(1.0\times10^{6})(10.0\times10^{-9})}{1.79\times(1.6\times10^{-19})}$$
$$= 3.49\times10^{16}$$