Chapter I

INTRODUCTION

1.1 Historical introduction

At the time of the invention of the first maser, (Microwave amplification by stimulated emission of radiation) there have been speculations concerning the possibility of extending the principle of maser to amplification and generation in the optical region. Most notable were the works of Schawlow and Townes[1], who explored the general physical conditions necessary for the operation of a laser (ligh amplification by stimulated emission of radiation). The first successful operation of laser was achieved by Theodore H. Maiman[2] in 1960.

Since Maiman's first announcement, many new laser materials have been discovered, including crystals other than ruby, glasses, plastics, liquids, gases and even plasmas.

The use of a gas to be a laser material was proposed by Javan[3] in 1959. The first gas laser with a He - Ne mixture as the active medium was operated in 1961 by Javan, Bennett and Herriot.[4]

Laser research and development proceeded at an unprecedented pace. New materials are being discovered weekly. More and more powerful lasers were constructed, and in turn suggested for new types of lasers.

1.2 Background material on radiation

Light, radiowaves, microwaves and heat is a form of electro-magnetic radiation. The electromagnetic spectrum is illustrated in figure 1[5] with the optical and visible spectrum shown enlarged.

All the electromagnetic radiation processes obey the same fundamental laws. Radiation processes resulted from the transitions between states in atoms. The frequency of the radiation emitted or absorbed is given by Bohr's frequency relation

$$h\nu \ = \ E_n \ - \ E_m \qquad \dots\dots\dots\dots(1)$$

where E_n and E_m are energies of states among which transition takes place.

The emission processes may be either spontaneous emission or stimulated emission, or both.

1.2.1 Emission processes.

Transition between levels in atoms without external causation are corresponding to the phenomenon of spontaneous emission. The total number of transitions per second, N_{nm}, from level n to level m in spontaneous emission is given by

$$N_{nm} \ = \ N_n A_{nm} \qquad \dots\dots\dots\dots(2)$$

where N_{nm} is the total number of transitions per second

N_n is the number of systems in the nth level.

A_{nm} is the spontaneous transition probability from n to m.

The power, W_{nm}, radiated at the frequency ν_{nm} is given by

$$W_{nm} \ = \ N_n \ (E_n - E_m) \ A_{nm} \qquad \dots\dots\dots\dots(3)$$
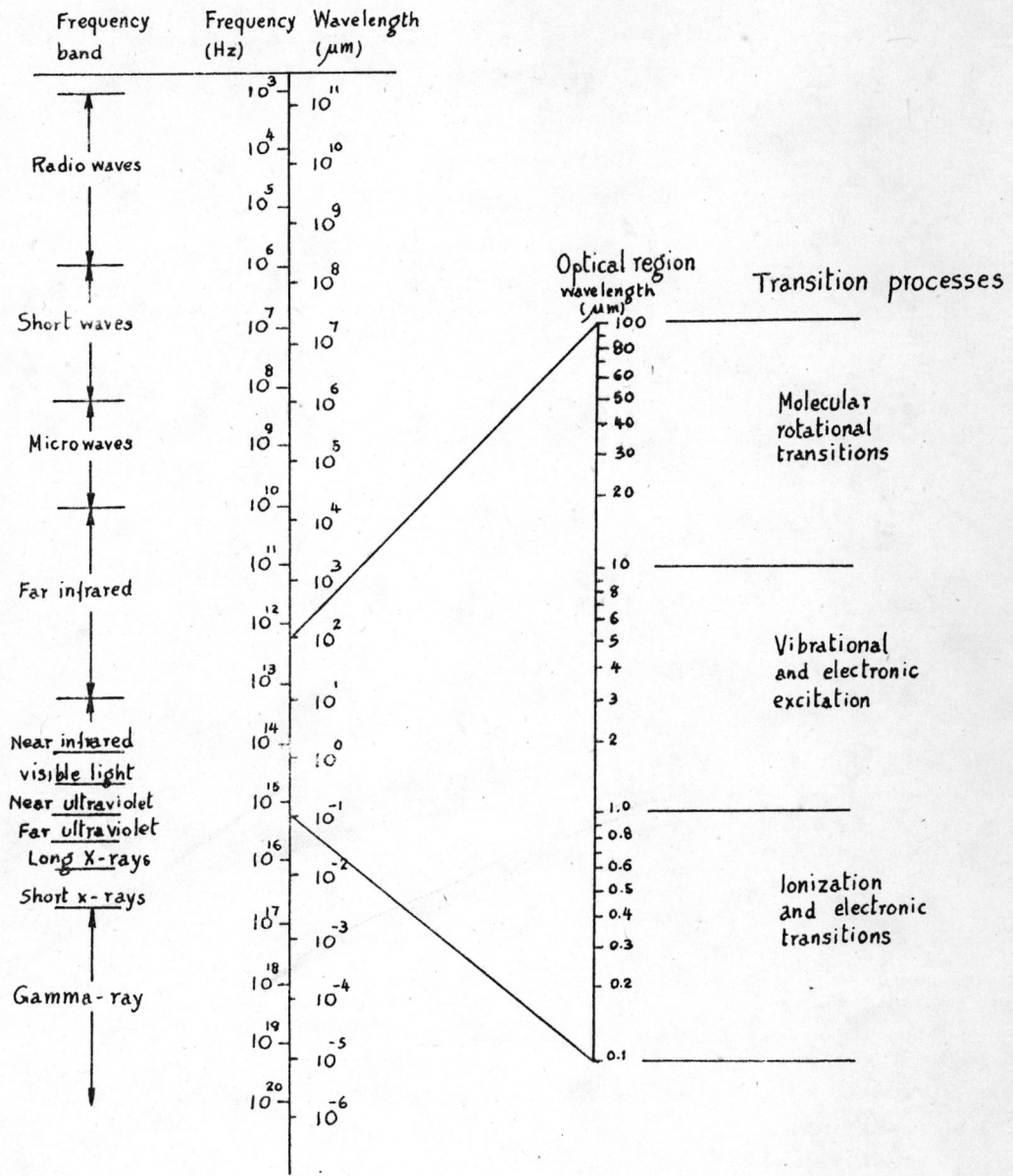
Figure 1   The electromagnetic spectrum.

where $\nu_{nm} = (E_n - E_m)/h$ .... (4)

Spontaneous radiation will emerge from the atoms in a random phase. The radiating atom is an incoherent source under spontaneous radiation.

Transitions between different energy levels take place not only spontaneously but also stimulatingly. Therefore the total probability that an atomic system will change in a unit of time from level n to level m is given by:

$$P_{nm} = A_{nm} + U_\nu B_{nm}$$ .... (5)

where P_{nm} is the total probabilily.

A_{nm} is the spontaneous transition probabilily.

B_{nm} is the stimulated transition probabilily.

U_ν is the radiation density at frequency ν_{nm}.

Conversely, the probabilily in transition from level m to level n (absorption) is given by:

$$P_{mn} = U_\nu B_{mn}$$ .... (6)

Radiation emitted from an atomic system in the presence of external causation consisted of two part. The part whose intensity is proportional to A_{nm} is the spontaneous radiation. The part whose intensity is proportional to $U_\nu B_{nm}$ is the stimulated radiation; its phase is the same as that of the stimulating external radiation. Systems concerning with stimulated radiation are coherent sources of radiation. The relations between the A's and B's are known as Einstein's relations.

$$g_n B_{nm} = g_m B_{mn} \quad \dots\dots\dots\dots (7)$$

And
$$A_{nm} = \frac{8 \pi h \nu_{nm}^3 B_{nm}}{c^3} \quad \dots\dots\dots\dots (8)$$

where g_n and g_m are the multiplicities of levels n and m.

At thermal equilibrium the distribution of the atoms among different states follows Boltzmann's law.[6] The number of atoms in state n will be

$$N_n = \frac{N_o e^{-E_n/kT}}{\sum_i e^{-E_i/kT}} \quad \dots\dots\dots\dots (9)$$

where E_n is the energy in state n; and all states of the same level will be equally populated.

System in a state of thermal equilibrium, stimulated absorption of light is predominant. For stimulated emission of radiation, the state of thermal equilibrium should be shifted so that there will be more higher energy than lower energy states.

The difference in density between the excited and ground states of an amplifying medium, the population inversion density, is the key factor deciding the possibilily of stimulated emission of radiation. The populations of the energy levels n and m are related by:

$$\frac{N_n}{g_n} = \frac{N_m}{g_m} e^{-(E_n - E_m)/kT} \quad \dots\dots\dots (10)$$

for $E_n > E_m$

The population inversion takes place only when

$$\frac{N_m}{g_m} < \frac{N_n}{g_n} \quad \dots\dots\dots (11)$$

Equation (11) is the necessary condition for population inversion.

The intensity of stimulated emission is not limited by the condition of black body radiation, see figure 2.
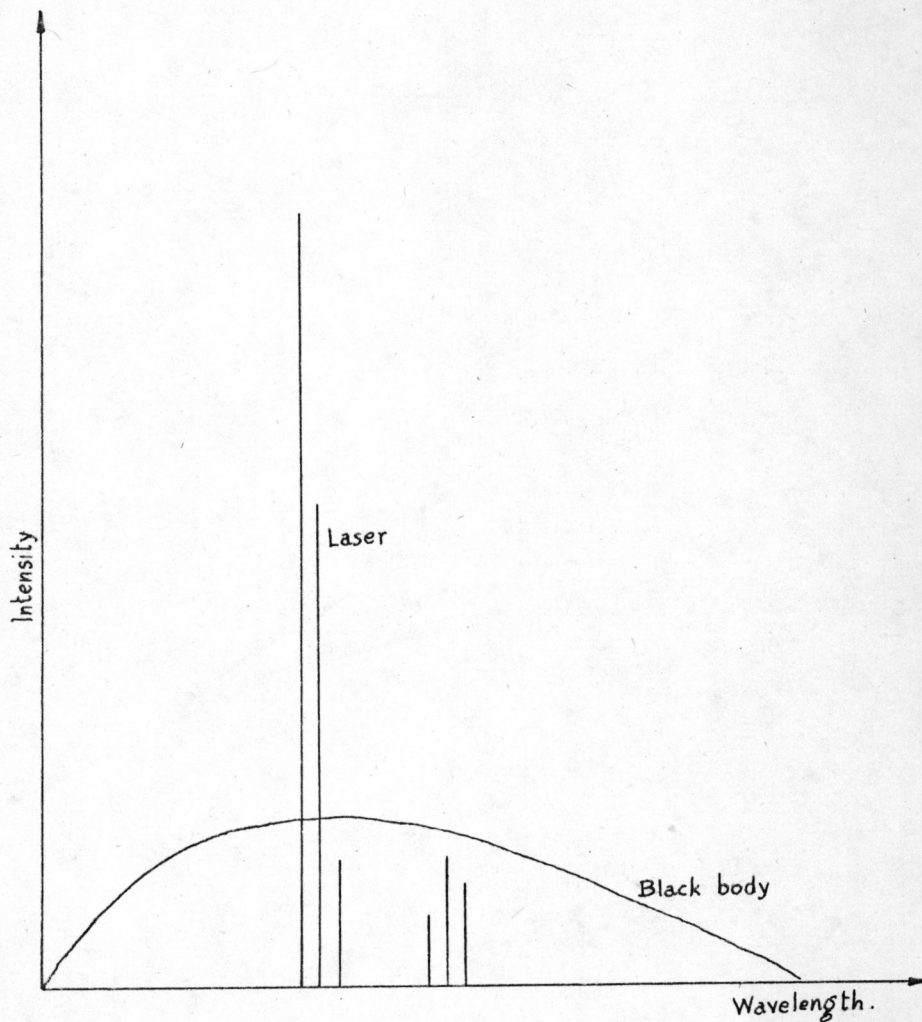
Figure 2   Relative intensity distribution of a black body and a laser.

1.2.2 Coherence of light.

In an ordinary light source, the individual atom radiates regular wave trains for short periods of time. In practice , the emitted light from a light source is composed of short wave trains, which are emitted at random times. If the source oscillates with frequency ν_0 and amplitude α for a time T lasting from $t = -T/2$ to $t = +T/2$, the wave disturbance will be

$$S(t) = \alpha \cos(2\pi\nu_0 t) \qquad /t/ < T/2$$
$$= 0 \qquad /t/ > T/2 \quad \ldots\ldots\ldots (12)$$

and having a Fourier spectrum.

$$S(\nu) = \int_{-\infty}^{+\infty} S(t)\, e^{-i\,2\pi\nu t}\, dt \ldots\ldots\ldots\ldots (13)$$

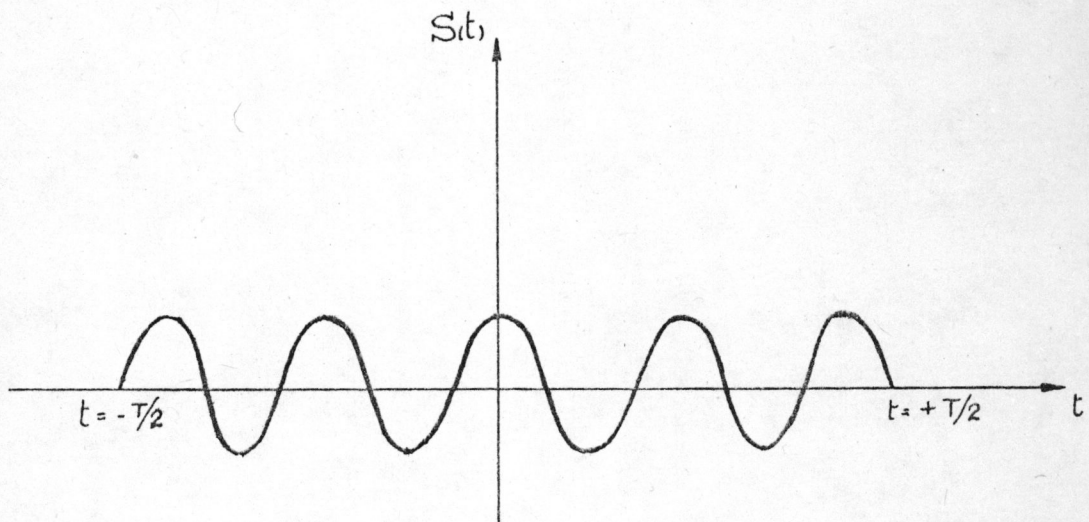The wave train of length $L = cT$ is shown in figure 3

Figure 3 Wave-train of length $L = cT$

Define   i)   The coherent time, T_{coh}, is the length of time for which

on average, an atom radiates continuously.

ii)   The coherent length, L_{coh}, is the length of the wave train

emitted during the coherent time.

So it can be obtained that

$$T_{coh} \cong \frac{1}{\Delta \nu} \qquad \qquad \cdots\cdots\cdots (14)$$

$$L_{coh} \cong \frac{\lambda^2}{\Delta \lambda} \qquad \qquad \cdots\cdots\cdots (15)$$

$$T_{coh} = L_{coh}/c \qquad \qquad \cdots\cdots\cdots (16)$$

The coherent time and the coherent length measure the temporal coherence[7]

of the light source.

The properties of stimulated emission enable spatial and temporally

coherent light output to be obtained not possible with sources of

spontaneous emission. Of all the properties of the laser, spatial coherence[8]

is the most outstanding one.

The spatial coherence of a light source is a measure of the

degree of phase correlation at two different points of space at a single

time. Spatial coherence is primarily dependent on the size of the source.

This can be tested by using the laser to repeat the classic double slit

interference experiment performed in 1806 by Thomas Young.[9]

Suppose that S_1 , S_2 are the apertures through which the radiation

can be passed and P is a point on the screen.

The intensity at the point P can be represented by[10]

$$\langle E_p^2 \rangle = \langle E_1^2 \rangle + \langle E_2^2 \rangle + 2\sqrt{\langle E_1^2 \rangle \langle E_2^2 \rangle} \left[\frac{\langle E_1(t)\, E_2(t-\mathcal{T}) \rangle}{\sqrt{\langle E_1^2(t) \rangle \langle E_2^2(t) \rangle}} \right] \quad \ldots \ (17)$$

where   i) E_1 and E_2 are electric fields due to S_1 and S_2

$$\text{ii)} \quad \mathcal{T} = \frac{/S_2\,P/ - /S_1\,P/}{c} \qquad \ldots\ldots(18)$$

Now it has been known that

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\ \ \gamma_{12} \qquad \ldots\ldots(19)$$

where γ_{12} the normalized correlation function of E_1 and E_2

$$\gamma_{12} = \frac{\langle E_1(t)\, E_2(t-\mathcal{T}) \rangle}{\sqrt{\langle E_1^2(t) \rangle \langle E_2^2(t) \rangle}} \qquad \ldots\ldots(20)$$

The degree of coherence can be obtained by considering on the factor γ_{12}

$$\gamma_{12} = 0 \qquad \text{no coherence}$$

$$\gamma_{12} = 1 \qquad \text{coherence}$$

$$0 < \gamma_{12} < 1 \qquad \text{partial coherence}$$

In Young's Experiment, a light source is usually small and is placed some distance from the slit. If the source is too large or too close to the slits, the pattern fails to appear.

For laser light, according to its spatial coherence, Young's experiment can easily be performed. The slits can be placed directly

against the surface from which the beam emerges and a clear inter-ference pattern will be obtained.[11]

1.3 Physical basis of a gas laser.

The physical basis of lasers, optical-quantum generators, is the amplification of light by stimulated emission of radiation. In gases, a net stimulated emission of radiation occurs only in con-dition referred to population inversion that is when

$$\frac{N_n}{g_n} \quad > \quad \frac{N_m}{g_m} \qquad \ldots\ldots\ldots\ldots\ldots (21)$$

and $E_m < E_n$ for some pair of level m and n

Whether population inversion is achieved depends on the rate of excitation and the decay rates of all levels involved in the cascade process.[12]

The rate of increase of population of atoms in the excited state N^* is given by[13]

$$\frac{d N^*}{dt} \quad = \quad n_e N_0 \left\langle \sigma_{ex} (E_k) V \right\rangle \ldots\ldots (22)$$

and the rate of deexcitation can be written as

$$\frac{-d N^*}{dt} \quad = \quad - n_e N_0 \left\langle \sigma_{deex} (E_k) V \right\rangle \ldots (23)$$

where n_e is the electron concentration.

N_0 is the concentration of atoms in the ground state

V is the relative velocity of atoms and electrons.

Several processes contribute to decay of a single level:

a) radiative process

b) collisions with electrons

c) collisions with other atoms

d) collisions with the walls of the gas chamber.

In addition to these phenomena the possibility of the resonance trapping of radiation must be considered, i.e. excitation of an atom to an occupied state by radiation emitted from another atom of gas. This phenomenon is clearly dependent on the pressure of the gas and the geometrical configuration of the gas chamber. It slows down the rate at which the atoms return to the ground states at the end of the cascade processes.

In gases, excitation by electron collision can be most conveniently accomplished in an electric discharge. When an electric discharge takes place in gas, ions and free electrons are formed; and population inversion can be established.

Population inversion can be established in a single gas by means of electronic excitation, but it is easier to succeed by using a mixture of gases, for example a mixture of He-Ne in Helium-neon laser.[14]

An electric discharge, used as a pumping source, may be transversed or longitudinal discharge and may be directly coupled with electrodes or indirectly coupled without electrodes.[15] A typical gas laser cavity is illustrated in figure 4 and 5
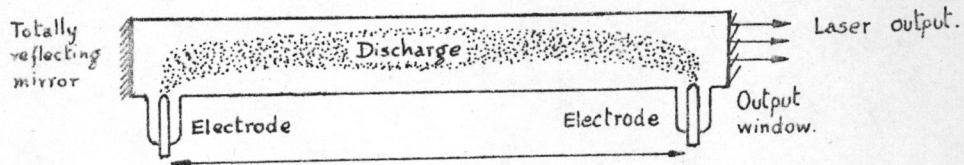
Figure 4   Typical gas laser cavity with axial discharge,
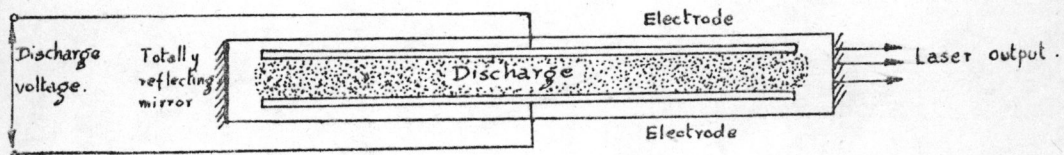

Figure 5   Typical gas laser cavity with transverse discharge,

The materials having absorbing centers with an appropriate set of discrete energy levels suitable for population inversion are called active media.   The active media may be either solid, liquids, gases or even plasma

In gases, transitions mechanism for laser emission may be either:[16]

a) Electronic transition in neutral atom.

b) Electronic transition in ions.

c) Vibrational transition in molecular gases.

1.4 Nitrogen gas laser.

Molecular nitrogen gas lasers have proved to be one of the most versatile ones. The first successful nitrogen gas laser was developed by Leonard.[17] Since then a large number of designs have been reported.[18-28]

By applying transversed electric discharge through nitrogen gas at a repetitive rate and at a proper pressure. A pulsed ultra-violet laser with wavelength of 337.1 nm is obtained.

In nitrogen gas laser, lasing transition is due to electron in nitrogen energy-transfer process. The lasing transition is in the triplet manifold,[29]

$$C^3\Pi_u \longrightarrow B^3\Pi_g + h\nu \text{ (3.68 ev)} \quad \text{...... (24)}$$
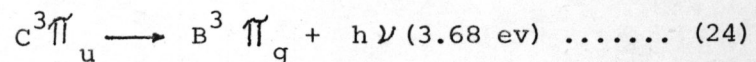
The nitrogen molecules are excited from the singlet ground state, $X^1\Sigma_g^+$ ground state, by electron impact in an electric discharge.

Transition between the $B^3\Pi_g$ levels and the $C^3\Pi_u$ level, resulting laser lasing with wavelength of 337.1 nm, see figure 6.
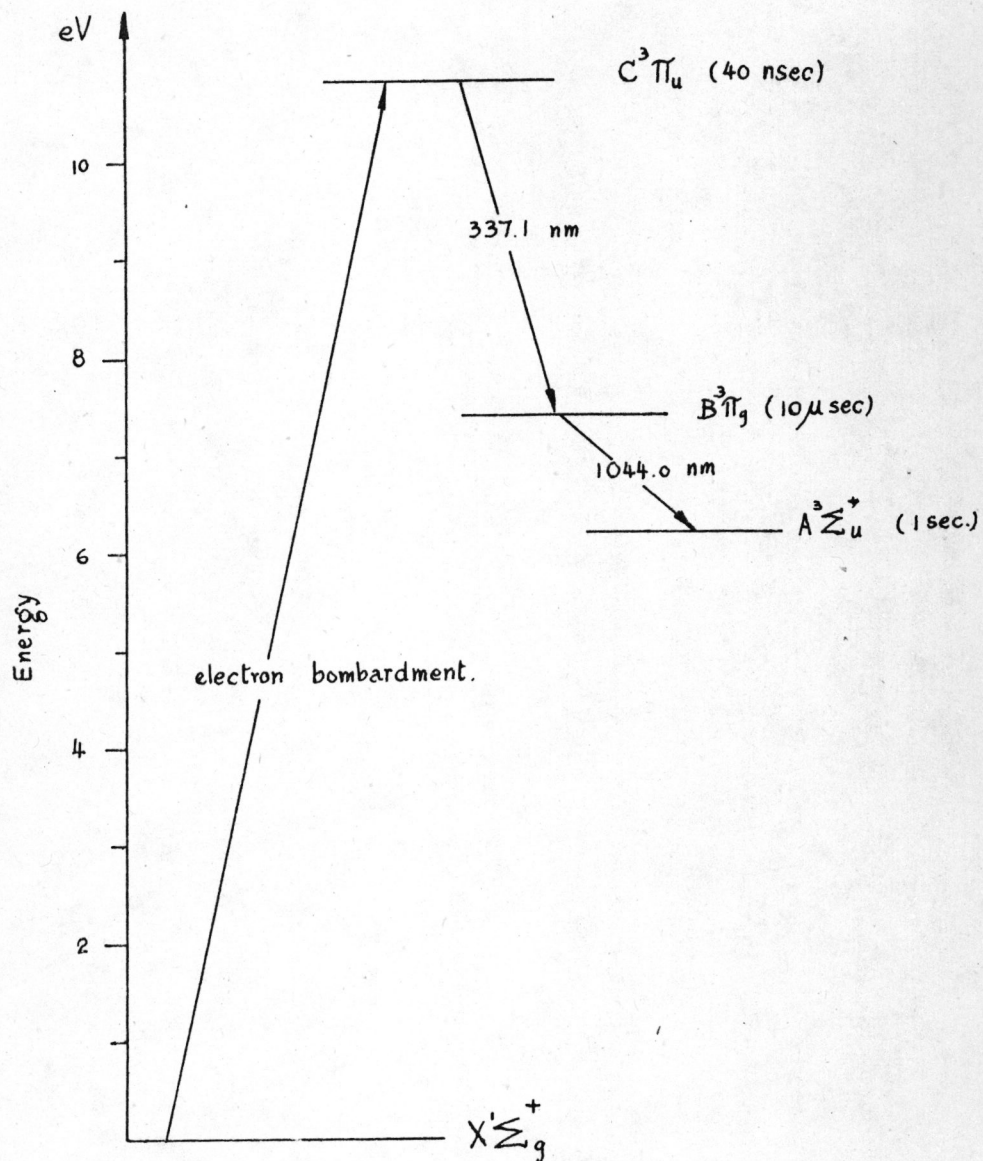
Figure 6   Highly simplified energy level diagram for molecular nitrogen.

1.5 The power of the laser

The power of the laser can be estimated via the calculation of the energy applied to the system, that is the energy stored in the capacitor in the Blumlein switching circuit.

The energy stored in the capacitor can be calculated by :

$$U = \tfrac{1}{2} CV^2 \qquad \dots\dots\dots\dots \quad (26)$$

where   U   is the energy stored in the capacitor

C   is the capacitance

V   is the charging voltage.

The energy of the laser is calculated from the energy stored in the capacitor via the conversion factor or the efficiency, η . The energy of the laser per pulse, U_r , is

$$U_r = U\eta \qquad \dots\dots\dots\dots \quad (27)$$

The power of the laser per pulse, P_r, will be

$$P_r = \frac{U_r}{\Delta t} \qquad \dots\dots\dots\dots \quad (28)$$

where Δt is the pulse width of the laser pulse.

1.5 Scope of this experiment

As have been mentioned, many new lasers materials have been discovered. Many gases have been used as laser materials. The noble gases - Helium, Neon, Argon, Krypton, Xenon have been the most thoroughly investigated and each has provided laser action at more than one wavelength.

Nitrogen gas provides laser action at a single wavelength. In the experiment, nitrogen gas has been selected to be a laser material. A nitrogen gas laser is to be constructed. Techniques in constructions of the laser chamber, the Blumlein switching pheno-menon and also the high voltage DC power supply will be discussed. The wavelength of the output pulses is to be determined and the coherence of the output beam is to be investigated and also the power of the laser will be estimated.