

CHAPTER - 2

NIGHT AIRGLOW EMISSIONS

2.1 Origin of Airglow

The earth's upper atmosphere is a natural unbounded laboratory wherein a wide variety of photochemical, chemical and dynamical processes occur continuously. As a result of these chemical reactions, the absorbed solar energy is released back in the form of radiation which manifest itself as a faint glow referred to as "airglow". The stored energy is released slowly and not dissipated quickly because, here is no "wall effect" in the upper atmosphere. So, the airglow is emission of photons from atmospheric constituents excited in a direct or indirect way by the electromagnetic radiation from the sun. All the three species, i.e., ions, electrons and neutrals participate in these chemical reactions. Many of these reactions place an atom, molecule or their ionic species in their excited states. These species de-excite to their ground states giving out photons in the ultraviolet to infrared band of the electromagnetic spectrum. Considerable numbers of these de-excitation processes are forbidden electric dipole transitions, and so they reach their respective ground states via metastable states. Different metastable have different life-times for de-excitation and hence their emission is very much height dependent. Below a certain height they are quenched owing to the prevailing higher collision rates and presence of particular type of species. The height of particular emission also depends on the densities of the reactants, the larger the

reactants, more the intensity. Owing to these factors various airglow emissions are centered at different heights. Hence, they provide information on the behaviour of the reactants at the altitude of their origin. Airglow emissions are in general, continuous and global in nature and are extremely weak. Their monitoring both by photometers and high-resolution spectrometers, have provided a wealth of information on the behaviour of the emitting regions, their temperature, densities and dynamics. This airglow emission is present at all times, both during night and day. The airglow during nighttime is called the “nightglow”, during twilight-time, the “twilightglow” and during daytime the “dayglow”. There are another phenomena similar to airglow, known as “aurora” which takes place in high-latitude regions only. However, airglow emissions occur at all latitudes.

The investigation presented in this dissertation provides the comprehensive measurements of “night airglow” emissions during clear ‘moonless’ nights from *Kolhapur* (16.8° N, 74.2° E, 10.6° N dip lat.). Scientific studies for the measurement of airglow were initiated by “*Rayleigh*” around 1920. So the unit of airglow emission, *Raleigh*, is named after him.

$$1R = 10^6 \text{ photons cm}^{-2} \text{ S}^{-1} \text{ (column)}.$$

The name airglow dates back from 1950 by “*Elvey*”. Basically the airglow emissions depend on the creation of an excited species and its subsequent return to ground state with a very small time delay. The

important immediate causes of airglow are the following:

- (1) Radiative recombination reactions emit a quantum of radiation.
- (2) Reaction products are often left in an excited state, and they then emit in returning to the ground state.
- (3) The excitation can be done by solar radiation, giving rise to resonance emissions.
- (4) Excited species can be produced by ionization product.

2.2 Classification Of Airglow

Airglow is non-thermal electromagnetic radiation emitted by the earth's atmosphere [1]. Though there is a characteristic difference between aurora and airglow, sometimes it is difficult to find the visual discrimination between weak aurora and airglow. So, the modified definition of airglow is; the airglow is the emission of photons from atmospheric constituents excited in a direct or indirect way by the electromagnetic radiation from the sun. The airglow is divided into three classes namely, nightglow, twilightglow and dayglow.

(A) Nightglow

The nightglow is the airglow occurring during night when all direct or Rayleigh scattered sunlight is practically absent. This occurs when the zenith angle of the sun is greater than approximately 110 degree. Nightglow is the faintest at zenith and is more intense towards horizon with maximum occurring 10 degree above horizon. This confirms airglow as an atmospheric phenomenon. During nightglow direct sunlight is practically

absent, the excitation of nightglow is indirect. Usually, the nightglow emissions are very weak in intensities and are of the order of few hundred Rayleighs only.

(B) Twilightglow

The emission of airglow at a time when sun is shining on the emitting region of the atmosphere from below and solar zenith angle is between 90 degree and 110 degree. The twilightglow is not prominent as dayglow but, it is more prominent than the nightglow. Most of the processes that lead to twilightglow are direct excitation by sunlight. The twilightglow are of two types, evening twilightglow and morning twilightglow. Evening twilightglow is more energetic because the sun sweeps the atmosphere during the daytime. The twilight may have intensities of several kilo Rayleigh.

(C) Dayglow

The dayglow is most prominent but, cannot be seen or very weakly seen due to the bright background of the Rayleigh scattered sunlight. So, it is the airglow emitted when sunlight enters the atmosphere from above. The solar zenith angle is between 0 and 90 degree. The radiation excitation by the direct sunlight is dominated by dayglow, though glows of the type emitted in nightglow are present. The dayglow intensities can range up to Mega-Rayleigh. In dayglow a strong diffuse background of continuous sunlight is present, which may have intensities in "R" per A° of the same or greater order of magnitude. The instruments for observing

airglow spectral emissions must be able to isolate the emission feature of interest and provide the intensity of the line emission alone. The dayglow photometer makes use of a narrow bandwidth interference filter to isolate the wavelength of interest, a low-resolution "F P etalon" used essentially as a spatial filter followed by unique mask system [2].

2.3 Photochemical Processes In the Ionosphere

Depending on the varying chemical composition with altitude, different ionization layers are produced within the ionosphere as a result of interaction between solar radiation and the dominant absorbing species. The ionosphere, starting from around 50 km above the earth's atmosphere, plays an active role in the studies of the atmospheric dynamics. Therefore, the ionosphere was subdivided into three layers known as D-layer (50-90 km), E-layer (90-130 km) and F-layer (~130-300 km) also subdivided in to F₁-, F₂-layers. These layers affect the propagation of radio waves. Molecular nitrogen and oxygen, helium and hydrogen are the major constituent of atmosphere. These species are ionized by absorbing quantum radiation, when energy exceeds the ionization potential of the species. The various chemical reactions taking place in the ionospheric regions are discussed below.

D-Region (50-90 km)

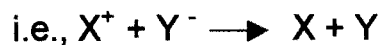
At D-region heights, the excited oxygen molecules are ionized by the EUV spectrum between 1027 Å° and 1018 Å°, the *Lyman-α* (1216 Å°) line of solar spectrum ionizes mainly nitric oxide, the hard x-rays < 10 Å°

and cosmic rays ionize all constituents.

The important processes due to ionization taking place in the D-region (50-90 km) are as follows:

(1) Ion-Ion Recombination:

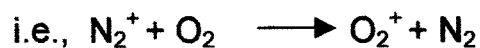
The atomic or molecular ions recombine to produce neutral atoms or molecules



Where, X and Y represents any molecules or atoms.

(2) Charge Exchange Reaction:

The N_2^+ is rapidly converted by this process to O_2^+



(3) Three Body Recombination:

In this process negative ions are produced

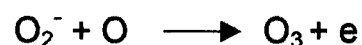


Where, M represents any other atom or molecule.

Here, the electron affinity is very small, so the electron is again detached by quanta of infrared or visible light.



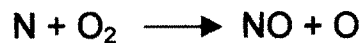
Also, below D-region there is one layer, ozonosphere, arises due to the following reaction.



Also,



The *Lyman* α -1216 A° ionizes only nitric oxide (NO). NO can be produced and destroyed by the following reactions



Where, M is the neutral particle.

E-Region (90 –130 km):

It is referred to as dynamo region and is formed due to photoionization by EUV (800-1026 A°), *Lyman* β - 1026 A° and X-rays from 10-100 A° . The EUV is absorbed by molecular oxygen to form O_2^+ . The X-rays ionizes all the constituents present there and a result N_2^+ , O_2^+ , O^+ , etc., are formed.

The E-region is full of molecular ions, so the dissociation recombination takes place and is as follows:

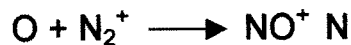
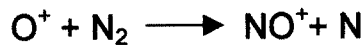
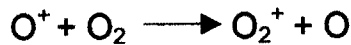


F-Region (130 – 300 km):

It is a region extending above 130 km and the principle source of photoionization is the EUV (170-911 A°) and also He-I and He-II lines at

304 Å and 984 Å respectively in the solar spectrum.

Here, the primary ions are in atomic forms, so they are first converted in to molecular ions by charge exchange reactions.



Above the F-layer heights, the radiative recombination is very important and fastest process.



Where, X is any molecule or atom.

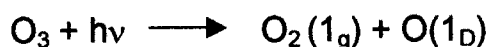
2.4 Observed Airglow Emissions

The airglow emissions are classified into three categories namely nightglow emissions, twilight emissions and nightglow emissions

2.4.1 Dayglow Emissions

There are three regions of emissions in the dayglow spectrum. They are ultraviolet dayglow emission, visible dayglow emission and infrared dayglow emission. In the ultraviolet, the OI triplet at 1302 Å, OI 1355 Å, the NO bands and N₂ second positive bands are the emission lines. In visible region the emission lines are N₂ first negative bands, OI 5577 Å and 6300 Å and sodium D-lines. The intense dayglow emission of the (O,O) band of the O₂ (1_g - 3_g) system observed by Noxon and Jones and OH emission comes under infrared region. When the sunlight incident on

the atmosphere, major excitation processes appears to be chemical reactions, fluorescent and resonant scattering, electron impact and photodissociation of ozone by sunlight (2000-3000 A°)

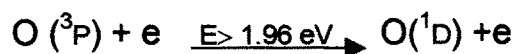


The atomic oxygen in one of its metastable states, O (1_D), has been used quite extensively for the investigations of thermospheric processes in comparison to any other metastable atmospheric species. Atomic transitions from their excited to ground states, via allowed channels, take place in a very short time (<10⁻⁸ sec). Certain species de-excite to ground state via an intermediate (metastable) state, as their direct transition violate the spectroscopic selection rules for electric dipole radiation. These are called the “forbidden” transitions. These metastable states have long lifetimes (from a second to several tens of seconds) and they play an important role in understanding the upper atmospheric chemistry and dynamics. For atomic oxygen *Frerichs* [3] predicted the wavelengths of transition from (1_D₂) to (3_P₂) or (3_P₁) to states to be 6299 ±5 and 6326 ±5 A° respectively. *Paschen* [4] observed these lines in the laboratory at 6300.06 and 6363.86 A°. *Bates and Dalgarno* [5] showed by theoretical calculations, that OI 630.0 nm be one of the strongest features in the dayglow spectrum. *Chamberlain* [6] showed that these emissions originate in a region between 143-300 km. Many review exist in the literature which elucidate the early studies and the processes that gives rise to this excited

states [1, 7- 9].

The $O(^1D)$ state is associated with an energy of 1.96 eV and has a life time of ~110 seconds. There are three important processes which results in the production of $O(^1D)$.

(i) Photoelectron impact (PE) on the ground-state oxygen, $O(^3P)$ [10,11]. When the energy of photoelectron is greater than 1.96 eV, the following reaction can take place.



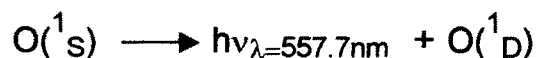
(ii) The second process is the photodissociation (PD) of molecular oxygen in the *Schuman-Runge* continuum (135—175 nm) of solar radiation [12].



(iii) The third process is the dissociative recombination (DR) of molecular oxygen ion [13].



There are other sources too that gives rise to the excited $O(^1D)$ state, but the overall contribution due to them is rather small as compared to the dominant processes discussed above [14]. They are:



The production of $O(^1S)$ state requires 4.12 eV of excitation energy and hence contribution of this reaction to $O(^1D)$ is believed to be very small.

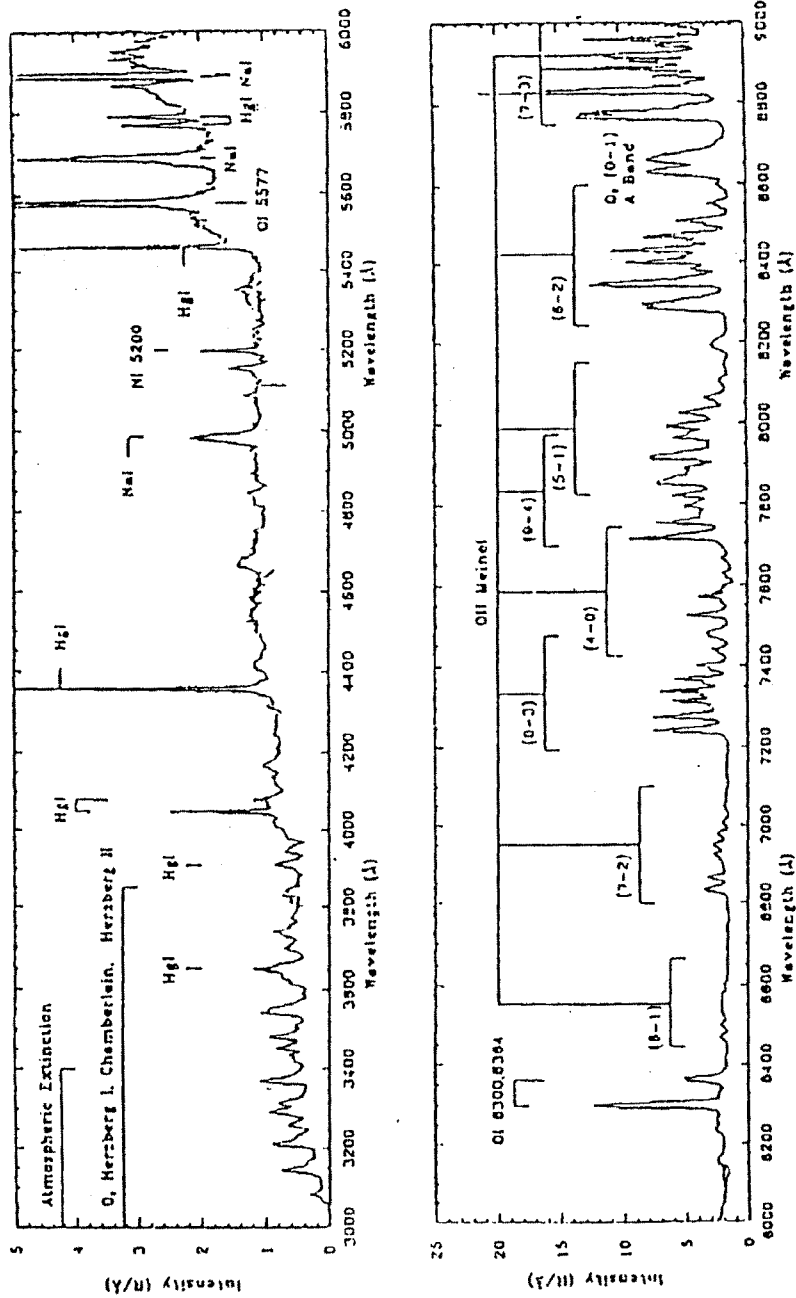
2.4.2 Twilightglow Emissions

The excitation processes for dayglow and twilightglow are same but the only difference is in the solar activity. Some of the lines present in the dayglow are also present in the twilightglow, but the oxygen green 557.7 nm line sometimes, may be, enhanced. Three alkali metals Li, Na and K have also been observed. During summer, ionized calcium's H- and K-lines are respectively observed. These lines are weak. The forbidden nitrogen doublet at 5200 Å being observed both in twilight and dayglow at around 200 km altitude. Two helium lines at 10830 and 3889 Å are observed around 500 km altitude excited by resonance scattering. Also the (0,0) band 3914 Å of the first negative system of N₂ is observed in twilight and these are totally absent in nightglow.

2.4.3 Nightglow Emissions

The first observed nightglow emission was a green line observed at 5577 Å and was identified as a forbidden line belonging to atomic oxygen in the year of 1925. *Slipher* showed the presence of yellow line at 5892 Å later turned out to be a sodium doublet 5890 / 5896 Å. After use of instruments with high detecting power more emission lines were detected. The accompanied figure shows all observed airglow spectrum lines and bands with approximate intensities and heights in the atmosphere.

The nightglow emissions are from two well separated layers of atmosphere i.e. from 80 to 130 km and 150 to 300 km. From lower regions



Observation examples of the spectrum of night airglow from the visible region to the infrared region

the emissions are green oxygen line (5577 Å) and weak continuum, the other containing emission from sodium and OH molecules. From higher regions the emissions are red oxygen lines (6300 / 6364 Å) and Ly γ and H-lines at atomic hydrogen. The emission from atomic oxygen provides wealth of information about ionospheric processes.

Bates and Nicolet first proposed production mechanism of OH emissions.



This is exothermic hydrogen-ozone reaction.

Where V is vibrational level and star (*) represents excited state.

Krassovsky (1963) proposed another reaction for OH ($V < 6$) is,

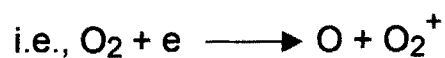


Above two reactions also produce sodium emission lines by replacing hydrogen atom with sodium atoms.

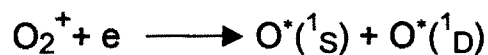
Hydroxyl (OH) emissions are used extensively for studies of the mesosphere. The emission originates from a layer near 87 km. The atmosphere has a number of levels and by comparing the intensity of two or more lines within one branch of a level, the rotational temperature of the molecule can be determined. By assuming that excited OH molecules are in thermal equilibrium with the atmosphere, this rotational temperature can be interpreted as kinetic atmospheric temperature.

2.4.4 Theory of Emission Of OI 630.0 nm And OI 557.7 nm Nightglow

Airglow emissions are generated when an excited species return to the ground state. During the nighttime the emission of 630.0 nm red line originates from the bottom side of the F-layer as a result of charge transfer from the majority of ions to form molecular ions.



This is followed by dissociative recombination to form $\text{O}^*(^1\text{D})$, the upper state of transition as follows.



Where star (*) represents excited state.

The $\text{O}^*(^1\text{S})$ state gives green line emission (557.7 nm) and also leads to 630.0 nm atoms. In a steady state, the rate of recombination of O_2^+ must be equal to its rate of production, which is proportional to the product of the density of electrons and O_2 density, assuming quenching to be present. Usually on the normal nights the density of O_2 at a given altitude does not vary rapidly with time and location. Hence the F-region nightglow enhancements must be caused by the variation of time or of location of the electron density. The changes in F-region height are more important than the changes in the electron density because, the constant for rate of reaction is temperature dependent. The changes in the

electromagnetic plasma drift ($\mathbf{E} \times \mathbf{B}$) and thermosphere neutral winds have a strong effect on the F-layer and the shape of electron density profile. The oxygen (O_2) density decreases exponentially with height with a scale height H of about $T \text{ [}^\circ\text{k]} / 32 \text{ km}$. The resulting profile of excitation rate versus height is a much thin layer (about 50 km) than the F_2 -layer with its peak at height where $d\ln N_e/dh = 1/H$ or situated well below the peak of the F-layer. Normally the OI 630.0 nm emission peak is situated about 1-scale height below the F-region peak in electron density.

The peak heights of emission of OI 630.0 nm vary between 230 to 270 km. The quenching by O_2 and N_2 of long lived state ($T - 150 \text{ sec}$) eliminates appreciable emission below 250 km, whereas the decrease in concentration of O_2 with altitude diminishes the production of OI 630.0 nm emission above 270 km considerably.

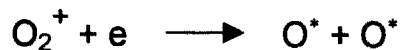
Ground based observation of the OI 557.7 nm emission provides the integrated intensity emanating from both mesospheric (E-region) and thermospheric (F-region) heights. For the studies of the mesospheric emissions, such as hydroxyl and molecular oxygen bands it is very important to have an estimate of the F-region component. The F-region component of the OI 557.7 nm intensity is approximately 20 % of the OI 630.0 nm intensity .

One important group of lines due to atomic oxygen includes the prominent green line at 557.7 nm (5577 A°) and the doublet red line at

630.0 / 636.4 nm (6300 / 6364 Å) actually a triplet, but the third line is weak. The energy levels concerned are shown in fig2.1. These lines are emitted when atomic oxygen in the 1s reverts to the 3p ground state in two steps via 1D . The first transition of lifetime 0.74 sec, gives the green line (5577Å) and the second of lifetime 110 sec gives the red line (6300/6364 Å). The UV line at 2972Å, corresponding to direct transition to the ground state, is too weak to be of interest of airglow.

The quantum yields, $F(^1s)$ and $F(^1D)$, of the excited states defined as the average no of $O(^1s)$ and $O(^1D)$ atoms respectively produced in each reaction.

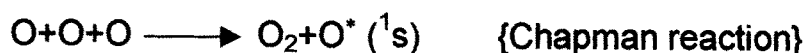
In the F-region the excited "O*" atoms come from the dissociative recombination between O_2^+ ion and electrons,



Where the star(*) represents excited state.

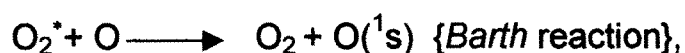
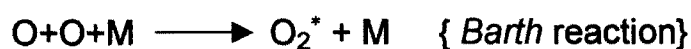
From each such reaction 7 eV energy is released, and both green and red line is emitted. The O_2^+ is produced from the charge transfer of O^+ with O_2 and observed 630.0 nm emission is proportional to the column integral of the product of O^+ and O_2 concentration.

In the E-region the excited "O" atoms comes from the reaction suggested by Chapman.



The O^* is in 1s state. At this lower height (E-region) the green line (5577 Å) is observed but the red line is missing. At 110 sec the lifetime of the intermediate 1D is so long that the energy is removed through collisions with other molecules before the red photon can be emitted. This process is called quenching.

Intensity of green emission is proportional to cubic power of concentration of oxygen atoms at 97 km altitude.



In both reaction schemes, the rate of production of $O(^1s)$ is proportional to third power of atomic oxygen density which peaks at about 97 km. At levels much below this quenching by O_2 and O compete with radiation at λ 558 nm.

Daytime emission of 557.7 nm has not been studied in greater details.

The atomic oxygen volume emission rate, $V_{557.7}$, calculated by using the following expression

$$V_{557.7} (\text{photon cm}^{-3} \text{s}^{-1}) = F(^1s) k_3 [O_2] [e] (A_{557.7}/A^1s)/G$$

Where $F(^1s)$ is the quantum yield $O(^1s)$ in O_2^+ dissociative recombination,

$G=[e]/[O^+]$, A_i is Einstein transition coefficient, K_i values are reaction rates.

By virtue of its mechanism, the green line is suitable for dynamical studies

and its doppler shift can be interpreted as the velocity of the neutral at that level. The intensity of the red-line from the F-region is found to be closely related to the F-region parameters, which might be expected since it arises from the part of the O^+ recombination process. However, the *Chapman* reaction at lower heights appears to have no correlation with the ionosphere.

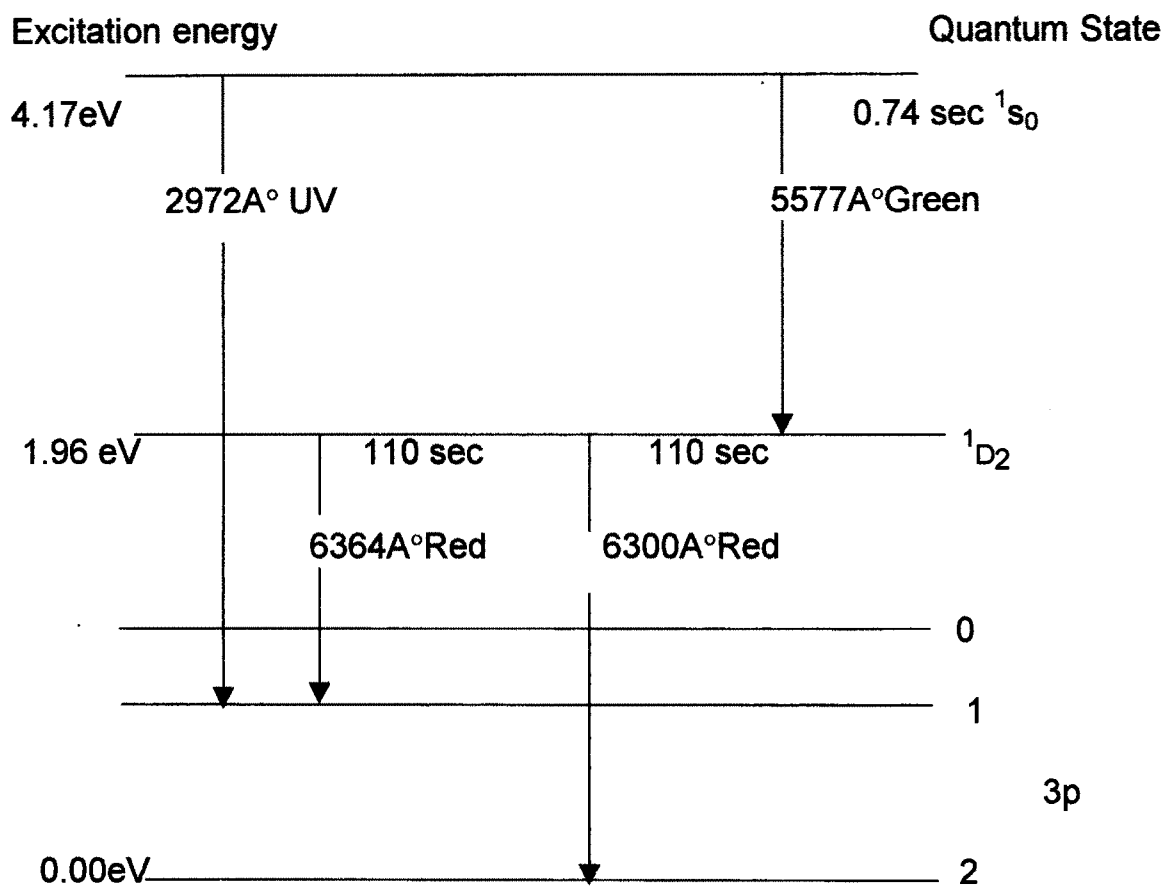


Fig-2.1- Energy Level Diagram.

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