Study and Analysis of Atomic Spectra

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DOI: 10.29322/IJSRP.10.11.2020.p10787
http://dx.doi.org/10.29322/IJSRP.10.11.2020.p10787

Abstract- When we look at objects giving off light (or reflecting light) we find three types of spectra. They are produced in different ways, and can actually tell us about the physical properties of the materials producing the spectra. These spectra are known as *"a continuous spectrum"* (or continuum emission), *"an emission line spectrum"* and *"an absorption line spectrum"*. Here, in this project we have tried to analyze all these spectra obtained from common light sources and $KMnO_4$. All the spectra were obtained with the help of a diffraction grating & spectrometer. Later, the spectra corresponding to different wavelengths and energy levels were observed. The electronic transitions and material involved in the formation of spectra were found out. Also, the wavelength of the light emitted, absorbed by a specific light source or molecule was determined along with the vibrational energy level of phosphor coating and energy lost in collision in case of a CFL.

Index Terms- Continuous spectrum, Energy levels, Absorption spectrum, Emission spectrum.

I. Introduction

We see very differently than we hear. With sound, we are able to pick out many different frequencies, i.e. different pitches. When different lights comes from different sources instead of seeing different colors we see all together as one color, which is made up of many different wavelengths of light. The electromagnetic spectrum, shown in Fig.1, shows a range of wavelengths, from gamma rays at 10^{-14} m to AM radio waves at 10^4 m. In this project, we considered the narrow band of wavelengths, $\sim 400 - 750$ nm, that make up visible light into consideration. Visible light primarily derives from artificial sources, such as Fluorescent, Incandescent and LED lights. By observing these common light sources along with $KMnO_4$ molecule, three different spectra were observed.

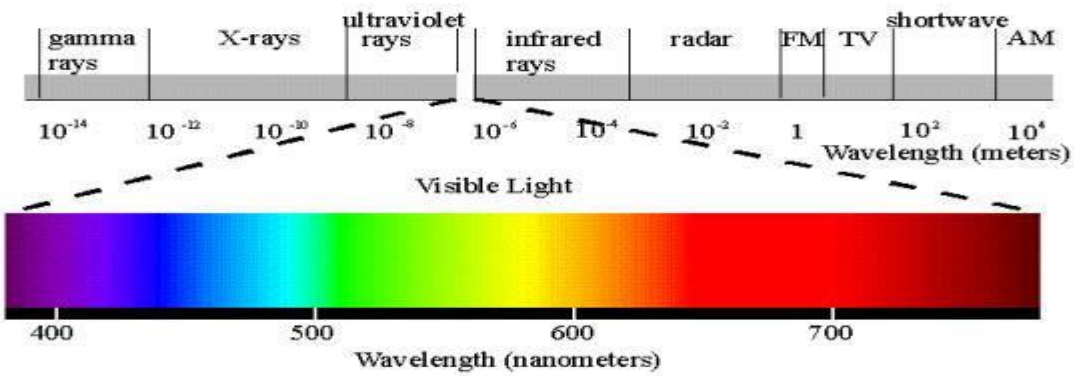

Fig 1: The electromagnetic spectrum with the visible light region blown up.

II. THEORY

In this project, we have explored light acting as a particle, known as *photon*. In the quantum model of the atom, electrons exist only in specific energy states. The photon ejected from an atom while electrons come down from higher energy state to lower energy state that is the difference between those states, so only certain amount of energies are emitted. The elements of Periodic table is where every element is uniquely identified by the number of protons in its nucleus. Quantum mechanics explains the energy states of the electrons in an atom. Each element in the periodic table has a specific electron energy levels as shown in Fig.2 (a), so for a given element only photons of specific energies can be emitted. Therefore, when we are measuring the emission spectrum of an element, only specific wavelengths of light are allowed and the pattern produced is unique for that substance. Atoms and molecules may change states when they absorb specific amounts of energy. When electrons are arranged in atomic orbitals they produced a pattern known as atomic states. An electron may absorb some certain amount of energy that is the difference between two orbitals so that to get and jump to that state. Molecular states consists of molecule's modes of vibration as well as rotation. Likely to the atomic orbitals these vibrational and rotational modes are also **quantized**, and by absorbing photon they may be excited. In both the cases, the **excited states** do not persist: after some time the atoms regain its original position that is the lower energy state. Generally in case of atoms the excited electron come back to lower state by emitting a photon. Similarly in molecules, the vibrational or rotational mode decays a photon. In the process of decays the photon direction may differ from original one. Most of these photon deviates ~45 degrees from the previous one. This clearly indicates that in case of light spectrum the gaps shows as that part of wavelength of light is absorbed. These gaps appear as black lines in an image of the spectrum known as absorption line spectrum.

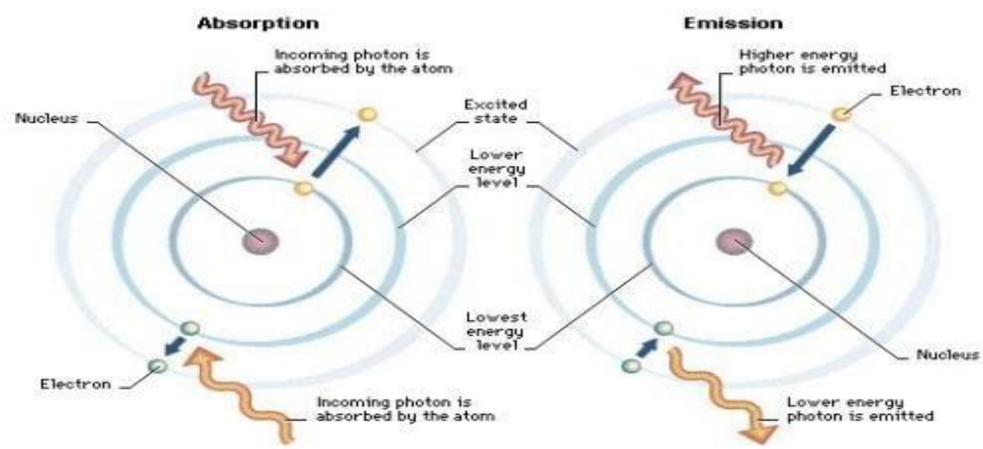

Fig 2(a): Absorption & Emission Spectra formation (Quantum Phenomenon)

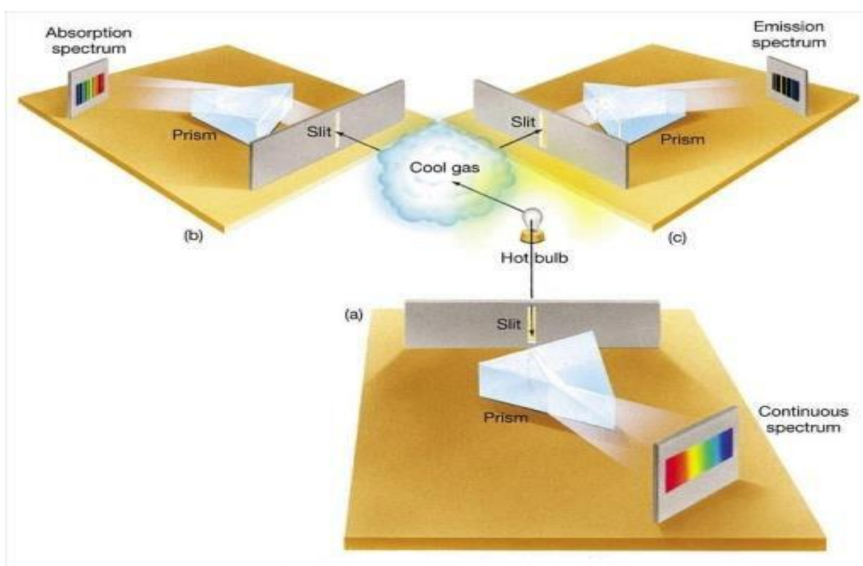

Fig 2(b): Formation of all the 3 types of spectra with the help of prism.

III. METHODS AND MATERIALS

CFL bulb, Incandescent bulb, LED bulb, $KMnO_4$ solution, spectrometer, prism, grating plate, optical levelling apparatus are required. Adjust the spectrometer and perform optical levelling of the spectrometer. After proper adjustments of the spectrometer, place the prism on the turntable and perform Schuster's method for setting up the spectrometer for parallel rays. Set the minimum deviation on the green line from the spectrum and focus the telescope and the collimator so as to get a fine image of the spectrum. Now replace the prism by a Diffraction grating (known grating element). Rotate the telescope in such a way that the slit can be seen directly through it. Get the θ value of this position. Add or subtract 90° from this θ value and rotate the telescope by that value. The telescope should be perpendicular to the plane of the collimator. Now rotate the turn table with the Diffraction grating mounted until the reflected image from the grating falls on the telescope cross wire. Place the cross wire at center to the reflected slit image. Measure the θ for this position. Add or subtract 45° from this position and rotate the prism table in such a way that the grating is parallel to the face of the collimator as it is rotated by 45°. Unclamp the telescope. The spectrometer is now set to take readings. Take readings for all dominant wavelengths of the spectrum. Use the formula $\lambda=\sin\theta/N$ to get the wavelengths of spectral lines. Calculate energy of these lines using $E=hc/\lambda$. The adjustments of the spectrometer and the diffraction grating (Experimental setup) is shown in Fig 3 (a, b, c).

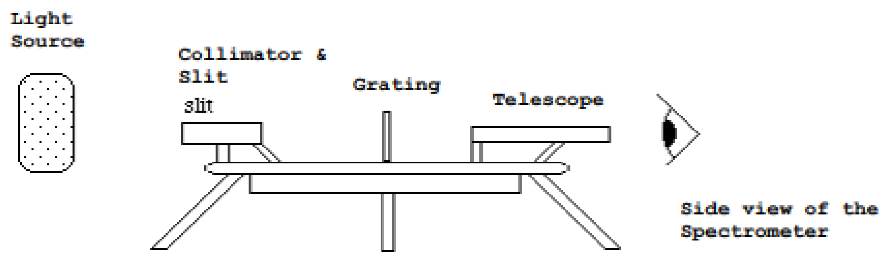

Fig 3(a): Optical setup of the spectrometer with the light source.

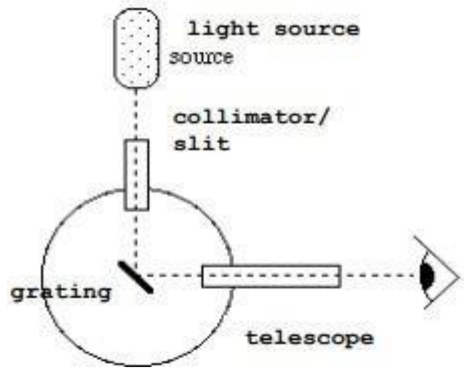

Fig 3(b): Setup of the telescope with the grating for parallel rays.

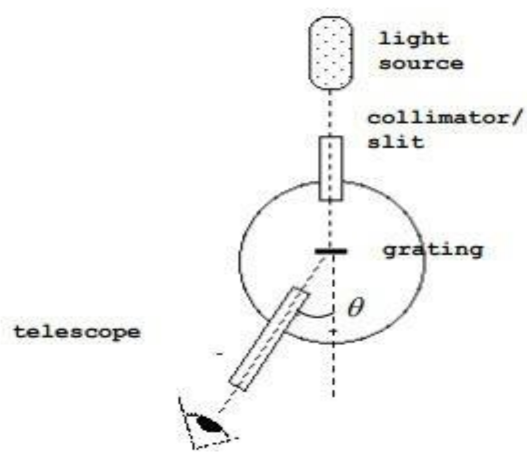

Fig 3(c): Observing the spectra and determination of θ.

IV. OVSERVATION AND DATA

No. of lines on grating = 15,000/inch, Grating element = N = 15,000/2.54 = 5905.51, therefore, $1/N = 1.693 \times 10^{-6}$ Least count of spectrometer = 1′.

Incandescent Lamp:

We observed a **continuous** spectrum. The data obtained from the Incandescent Lamp spectra is tabulated below-
Direct Reading: Window X: 126°36′ & Window Y: 306°35′.

Table 1: Data obtained from Incandescent Lamp

color Band	X	Y	Θ_1	Θ_2	Mean Θ	λ=sinθ/N (nm)	E=hc/ λ (eV)
Start (Violet)	141°6′	321°5′	14°15′	14°30′	14°23′	420.55	2.94
End (Red)	150°42′	330°39′	24°6′	24°4′	24°5′	693.1	1.78

CFL Lamp:

In this case we observed an **emission line** spectrum. The data obtained from the CFL Lamp spectra is tabulated below:
Direct Reading: Window X: 126°36′ & Window Y: 306°35′.

Table 2: Data obtained from CFL Lamp

color	X	Y	Θ_1	Θ_2	Mean Θ	λ=sinθ/N (nm)	E=hc/ λ (eV)
Red	149°50′	329°40′	23°14′	23°5′	23°10′	666.03	1.86
Orange 1	147°57′	327°53′	21°21′	21°18′	21°20′	615.90	2.01
Orange 2	147°27′	327°32′	20°51′	20°57′	20°54′	603.95	2.05
Yellow 1	146°46′	326°53′	20°10′	20°18′	20°14′	585.51	2.11
Yellow 2	146°22′	326°47′	19°46′	19°54′	19°50′	574.40	2.15
Green 1	145°36′	325°39′	19°0′	19°4′	19°2′	552.11	2.24
Green 2	144°7′	324°14′	17°31′	17°39′	17°35′	511.44	2.42
Blue	143°17′	323°18′	16°41′	16°43′	16°42′	486.50	2.54
Blue Green	142°49′	322°47′	16°13′	16°12′	16°13′	472.8	2.62
Violet	141°35′	321°42′	14°59′	15°7′	15°3′	439.6	2.82

LED Lamp:

Here, we observed a **continuous** spectrum. The data obtained from the LED Lamp spectra is tabulated below: Direct Reading: Window X: 126°36′ & Window Y: 306°35′.

Table 3: Data obtained from LED Lamp.

color Band	X	Y	Θ_1	Θ_2	Mean Θ	λ=sinθ/N (nm)	E=hc/ λ (eV)
Start (Violet)	141°16′	321°8′	14°40′	14°33′	14°36′	426.75	2.90
End (Red)	150°20′	330°16′	23°44′	23°41′	23°42′	680.49	1.82

$KMnO_4$:

Case 1: Here, we observed an **absorption line** spectrum by using LED as light source. The data obtained from the spectra of $KMnO_4$ is tabulated below: Direct Reading: Window X: 138°30′ & Window Y: 318°29′.

Table 4(a): Data obtained from $KMnO_4$ using LED Light

Dark Band	X	Y	Θ_1	Θ_2	Mean Θ	λ=sinθ/N (nm)	E=hc/ λ (eV)
Start	155°5′	335°5′	16°35′	16°36′	16°36′	483.67	2.56
End	159°42′	339°45′	21°12′	21°16′	21°14′	613.14	2.02

Case 2: We observed an **emission line** spectrum by using CFL as light source. The data obtained from the spectra of $KMnO_4$ is tabulated below: Direct Reading: Window X: 138°30′ & Window Y: 318°29′.

Table 4(b): Data obtained from $KMnO_4$ using CFL Light

color	X	Y	Θ_1	Θ_2	Mean Θ	λ=sinθ/N (nm)	E=hc/ λ (eV)
Red	159°19′	339°6′	40°49′	20°37′	20°43′	598.89	2.07
Blue	154°3′	334°18′	15°33′	15°49′	15°41′	457.56	2.71

V. DATA ANALYSIS, RESULT AND DISCUSSION

Incandescent Lamp: When electric current is passed through a tungsten filament wire it gets heated and dose glows/incandesces which results in producing light. The composition of an incandescent lamp is shown in Fig 4.

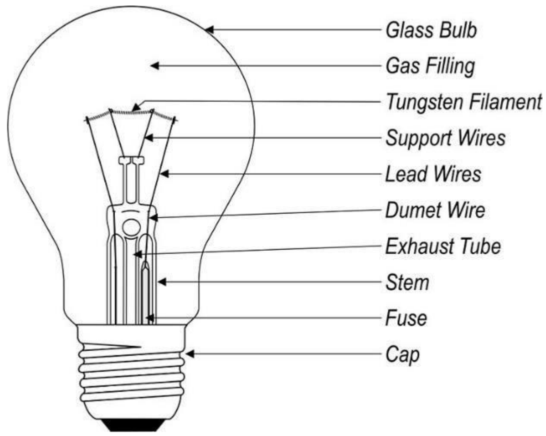

Fig 4: Components of Incandescent lamp.

As observed, the hot filament produces is a "continuous" spectrum, because all the wavelengths of light are present (the spectrum has no breaks). The filament acts as a **blackbody**, emitting all possible wavelengths of light similar to the sun (Planck's Law). When filament burns, chemical reaction called combustion in which large amount of energy is released. Some part of energy is heat, while other is light. Substances when heated emits light because the atoms present gains energy and gets excited, which results in spectrum formation. Heating makes the atom unstable, after sometime they give off the energy as photon and become stable. Heated electrons in the continuous energy bands of tungsten becomes excited and transition takes place to lower energy state. As mercury vapor lamp these spectrums are continuous. As it considered spectrum in visible range but still have energies near Infrared region.

From the obtained spectra, it was quite evident that the wavelengths in the range from **420.55 nm** to **693.1 nm** were emitted by the incandescent lamp. However, it is important to note that the light bulb emits a lot of infrared radiation which is not visible to the human-eye. These infrared radiations lead to the generation of heat along with light in case of an incandescent lamp.

CFL Lamp: The light produced from CFL is different than that of Incandescent Lamp. In a CFL, an electric current is passes through a argon and mercury vapor contain tube. This creates invisible ultraviolet light that excites a fluorescent coating (called phosphor) inside the tube, which then emits visible light. The composition of CFL lamp is shown in Fig 5.

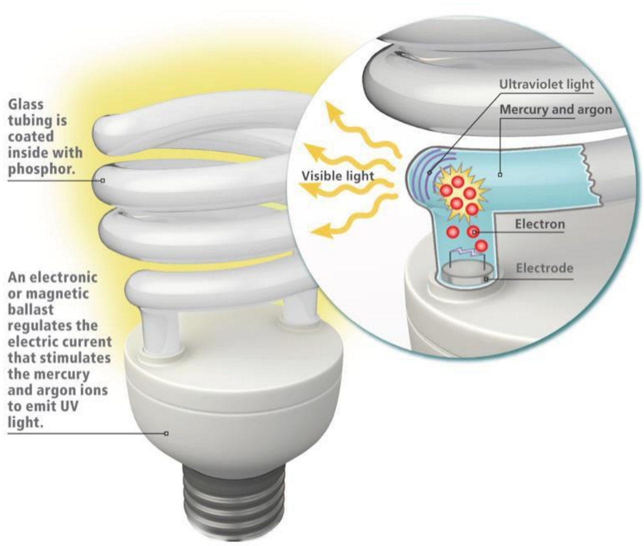

Fig 5: CFL Lamp with its composition labelled.

Molecule in excited electronic state can lose energy and return to its ground state in various ways. The molecule may simply emit a photon of the same frequency as that of absorbed photon, thereby returning to the ground state in a single step. There is one more possibility that the molecule gives up some of its vibrational energy in collisions, so the downward radioactive transition originates from a lower level in the upper electronic state. This phenomena is known as Fluorescence. Therefore the fluorescence radiation is of lower frequency than that of the absorbed radiation. This is the working principle of CFL lamp. From the observations, it was observed that only certain photons having discrete energy levels were visible which produces an emission line spectrum. The following results is obtained by evaluating the difference in energy levels:

Table 5: Energy level data of CFL Light

Energy levels	Energy difference (eV)
Red – Orange 2	0.19
Orange 2 – Yellow 2	0.1
Yellow 2 – Green 2	0.27
Green 2 – Blue	0.12
Blue - Violet	0.28

Energy conservation law is taken into consideration which explains the following equations:

Energy (UV) = Energy (Color) + Energy (Collisions with phosphor)

We know, λ (UV) = 254 nm, Similarly, E (UV) = hc/ λ = **4.88 eV**, the equation of energy lost in collision for each photon can be given by:

Energy (Collisions with phosphor) = Energy (UV) - Energy (color)

From the above equation the following table (Table 6) is tabulated:

Table 6: Energy loss of different photons

Color	Energy (color) (eV)	Energy (Collisions with Phosphor) (eV)
Red	1.86	3.02
Orange 1	2.01	2.87
Orange 2	2.05	2.83
Yellow 1	2.11	2.77
Yellow 2	2.15	2.73
Green 1	2.24	2.64
Green 2	2.42	2.46
Blue	2.54	2.34

Blue Green	2.62	2.26
Violet	2.82	2.06

From Table 6 the **average energy lost during collision** was found **= 2.598 eV**

Hence, obtained spectra from CFL as a light source, photons were emitted which leads to the formation of emission spectra and the energy levels and wavelengths were calculated with the energy which is lost when the CFL glows. Energy is lost due to collisions taking place between phosphor material and the charged ions.

LED Lamp: The spectrum is produced either by a single Light-emitting-diode, or combinations of phosphors and LED, or several different LEDs. The formation of continuous spectrum is explained by band theory. The general mechanism of LED is explained in Fig 6. LED is basically a sandwich of semiconductors. Semiconductors can either be natural elements (such as Si or Ge) or carefully engineered semiconductors. The sandwich of the semiconductor creates a flow of electrons, which leads to the production of photons having certain wavelength, which depends on the electronic structure of the semiconductors. In the LED/phosphor case, usually blue LED gives off light which is then absorbed by the phosphors to produce the other colors of the spectrum. In multiple LED case, there are different types of LED which when combine, produces all the colors of the spectrum.

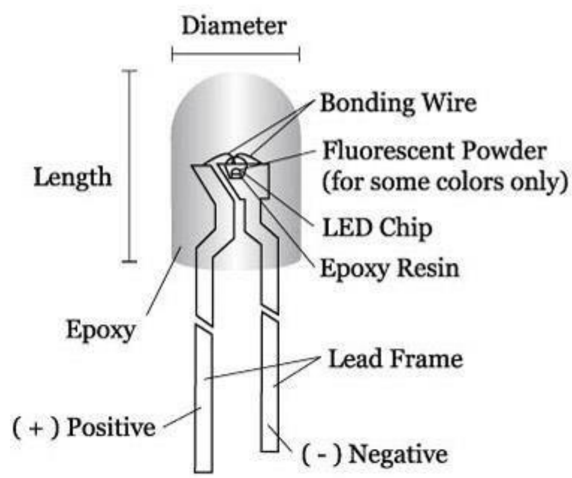

Fig 6: Components of LED Lamp.

The material used in LEDs is basically **aluminum-gallium-arsenide** (AlGaAs) as shown in Fig 6. In its original state the atoms are held tightly. The conduction of electricity becomes impossible due to lack of free electrons. The balance of material is disturbed by introducing some extra amount of atoms called doping. These doping creates some extra electrons or sometimes sucks the available electrons and creates holes which leads to create P-type semiconductors. Due to the property of semiconductor, current will not travel in opposite directions in the respective cases. This explains that the intensity of light emitted from source (LED) will depend on the energy level of emitted photons which in turn will depend on the energy released by the electrons. To make an electron shift from lower to higher orbits, energy level needs to be lifted. Conversely, when the electrons fall from the higher to lower orbits, energy is released. The above phenomena are well exploited in LEDs. In P-type doping, electrons fall from higher to lower orbitals releasing energy in form of photons that is light. The far the orbitals, the greater the intensity of emitted light.

From the obtained spectra, it was clear that the wavelengths in the range from **426.75 nm** to **680.49 nm** were emitted. LED bulbs also have higher efficiency as compared to an incandescent bulb due to its ability to provide light without generation of heat and also as it does not contain any toxic substances.

$KMnO_4$:

Case 1: An absorption spectrum of $KMnO_4$ was obtained using LED source. It was noted that a band of light was absent in the spectrum suggesting that the photons of that band were completely absorbed by the $KMnO_4$ solution. An absorption spectrum shows how much light is absorbed for a range of wavelengths.

It was determined that solutions of analyte may absorb light of different wavelengths. When we put something in front of our eyes that leads to absorption of color from the incoming light and show us the same. For instance, the analyte (potassium permanganate or $KMnO_4$) absorbs light in the green region of the visible spectrum as shown in Fig 7, allowing red and blue light pass through as shown in Fig 8. The mixture of blue and red is perceived by the eye as the typical purple color of $KMnO_4$.

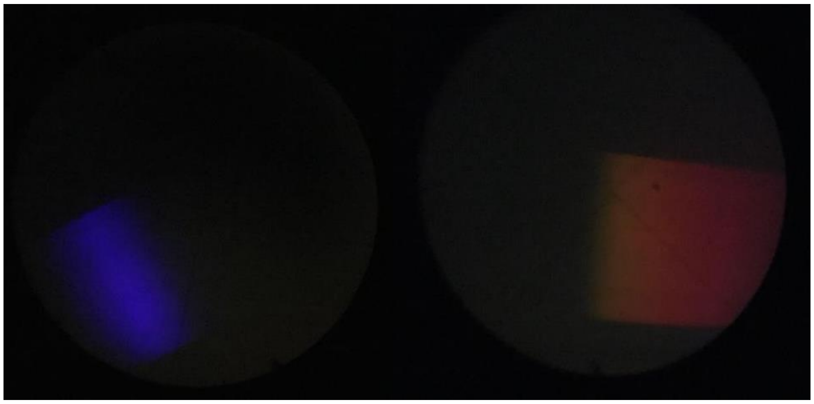

Fig 7: Absorption spectra of $KMnO_4$ solution.

Hence, it was noted that the wavelengths in the range from **483.67 nm** to **613.14 nm** which predominantly involves green color were completely absorbed by the solution and rest all photons were emitted.

Case 2: An emission spectrum of $KMnO_4$ was obtained with the help of CFL source. It was noted that certain photons having specific energies were emitted by the $KMnO_4$ solution. The emitted line spectrum observed is shown in the Fig 8 which shows the blue and red photon of specific energies **2.07 eV** and **2.71 eV** respectively.

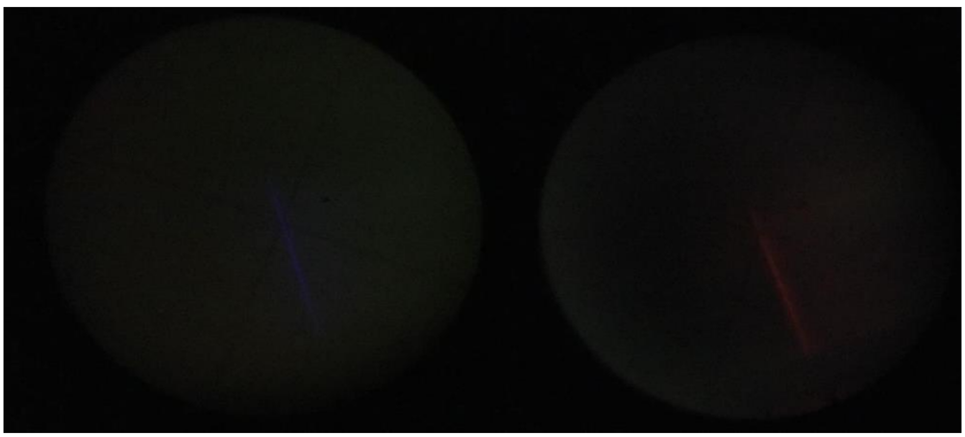

Fig 8: Emission spectra of $KMnO_4$ solution.

VI. CONCLUSION

A comparative study of the three different types of spectrums obtained from common light sources and $KMnO_4$ was successful. Some useful insights were obtained while observing the continuous, emission spectrums and the energy transitions leading to their formation. For Incandescent light source the wavelengths generated was found to be in the range from **420.55 nm** to **693.1 nm.** For CFL light source, the average energy loss during collisions was found out to be **2.598 eV**. Also, for LED source the photons produced were having wavelengths in the range from **426.75 nm** to **680.49 nm.** Subsequently, for $KMnO_4$ solution it was observed that it absorbs light in the green region of the visible spectrum in the range from **483.67 nm** to **613.14 nm** and emits red and blue light having energies **2.07 eV** and **2.71 eV** respectively.

Acknowledgment

I feel great in writing report acknowledgement and I will like to say some good words for those who stood by my side in my writing task. I am extremely grateful to the many people who have helped me in the study for and preparation of this experiment. First and foremost, I want to thank my professor Dr. Ramesh Thamankar, for his guidance, help and motivation in this experiment. The joy and enthusiasm he has for research was motivational for me, during this project time. Then I would like to thank my group mates. Their enthusiasm for pursuing daunting problems in physics at the highest levels of scientific integrity and rigor has been a constant source of inspiration, excitement, advice, and guidance throughout my experiment. I deeply thank them for the unprecedented freedom he offered to explore my intellectual curiosity in our experiments, and for fostering my capacity critically as an independent researcher.

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