LIGHT-MATTER INTERACTION

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CONTENTS

OBJECTIVES

1. **Determine the emittance spectra of diverse light sources and obtain the spectral power distributions of blackbody radiators within the visible light range.**
2. **Capture images illustrating various light-matter interactions and provide comprehensive explanations for each observed interaction.**
3. **Investigate human eye sensing properties by measuring near points for each eye and exploring scotopic and photopic vision through the induction of the Purkinje effect.**
4. **Obtain the technical specifications of different models of camera.**
5. **Evaluate visual acuity by measuring the fovea angle.**

METHODOLOGY

01 LIGHT SOURCES

1. Take pictures of various light sources around us and search for their corresponding emittance spectra.
2. Compute the spectral power distribution of a blackbody radiator at temperatures: 1000K, 2500K, 5400K, 6500K for the visible range (350-750 nm). This is given by Planck's Law shown in the expression below

$$B(\lambda, T) = \frac{2hc^2}{\lambda^5 (\exp(hc/\lambda kT) - 1}$$

METHODOLOGY

02 SURFACES

Using our phone cameras, we took pictures of different light-matter interactions. These pictures were taken from natural sceneries that we see everyday, and from experiments conducted in our physics laboratory classes.

Figure 1. Rayleigh Scattering

METHODOLOGY

03.1 NEAR POINT

Figure 2 displays the setup for the near point measurements for each eye. A member covered one of their eyes, ensuring it was neither closed nor squished. An object with small text printed on it was held close to the other eye by the member. Gradually, the object was moved away until the point at which the eye began to regain focus. Subsequently, another member measured the distance between the eye and the object using a ruler. These measurements were conducted for each eye of all the members.

Figure 2. Measuring the near point of each eye.

METHODOLOGY

03.2 SCOTOPIC & PHOTOPIC VISION

We created a dark enclosure using a black cloth. Inside the enclosure, we placed patches of different colors (**ROYGBIV**) in random order. Each member spent 5 minutes inside the dark enclosure with their eyes closed. The first color that each member saw upon opening their eyes was recorded. Figure 3 shows the setup.

Figure 3. Experiment setup using dark enclosure for scotopic vision.

METHODOLOGY

04 CAMERAS

The technical specifications of each camera member were downloaded. Specifically, the sensor sizes were collected, along with the camera's technical reviews found on the internet.

The following are details of each member's camera

- **Nicholas William**: Xiaomi Pocophone F1
- **Johnenn**: Xiaomi Redmi Note 11
- **Jonabel Eleanor**: Apple iPhone 13 mini
- **Julian Christoper**: Xiaomi Mi 11 Lite

Figure 4. Different phone cameras of each member.

METHODOLOGY

05 VISUAL ACUITY

A piece of paper with small text of font size 12 was taped on the wall. A member stood 25 to 50 cm from the wall and fixated on a letter, while another member covered the succeeding letters. One by one, the letters were uncovered and the member identified each letter until the next letter was unidentifiable. The distance from the fixation point to the last discernable letter was recorded and the angle from the center line to that letter was calculated for each member. The equation for the angle is

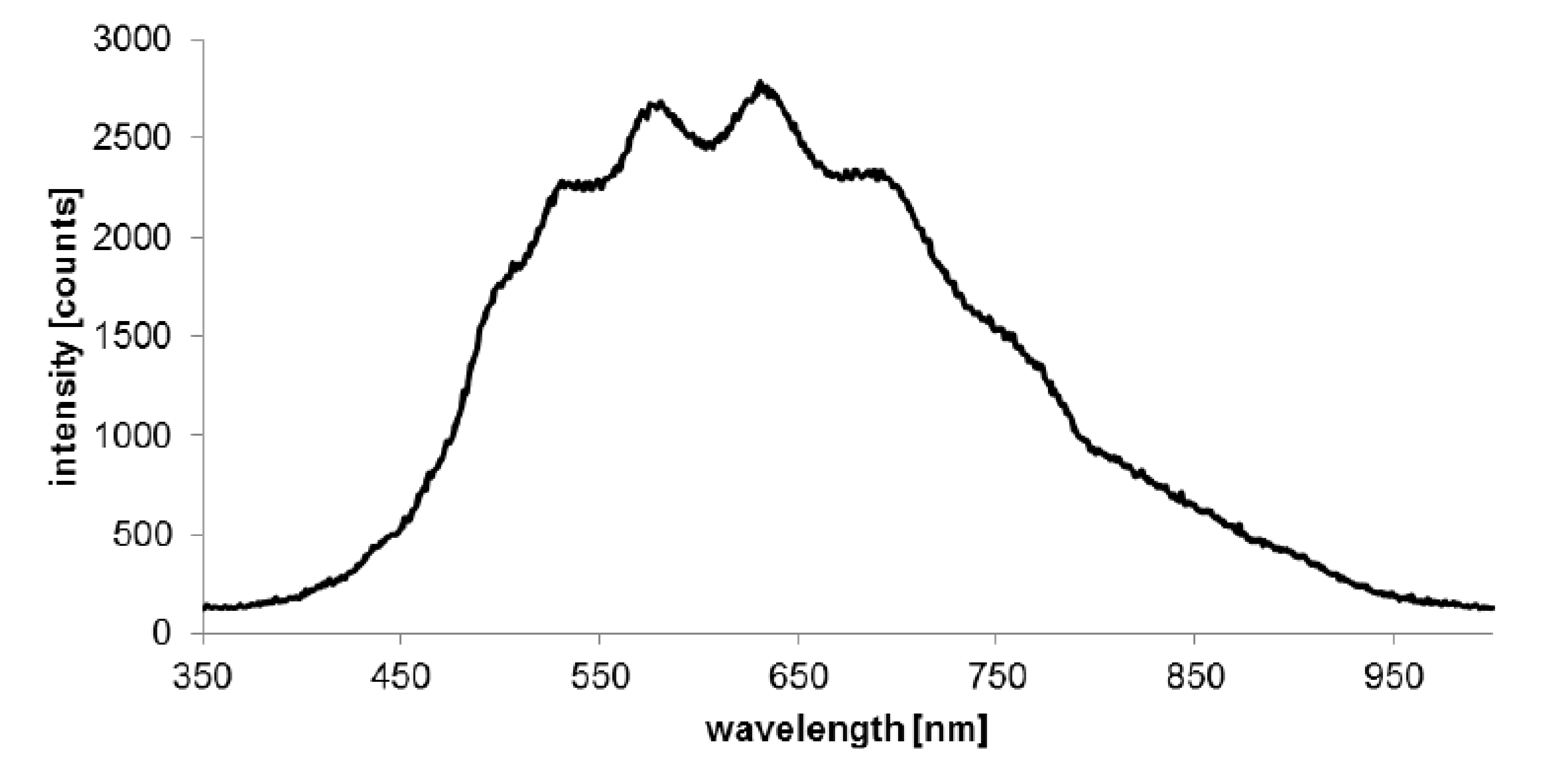
$$angle = \tan^{-1}\left(\frac{L}{x}\right)$$

where L is the eye-wall distance and x is the distance of the fixation point to the last discernable letter.

Figure 5. Experiment setup for visual acuity.

RESULTS & ANALYSIS

01 LIGHT SOURCES: HALOGEN BULB



https://www.researchgate.net/figure/Measured-spectrum-of-a-tungsten-halogen-lamp_fig2_273454510

Figure 6. Tungsten halogen bulb emission spectra

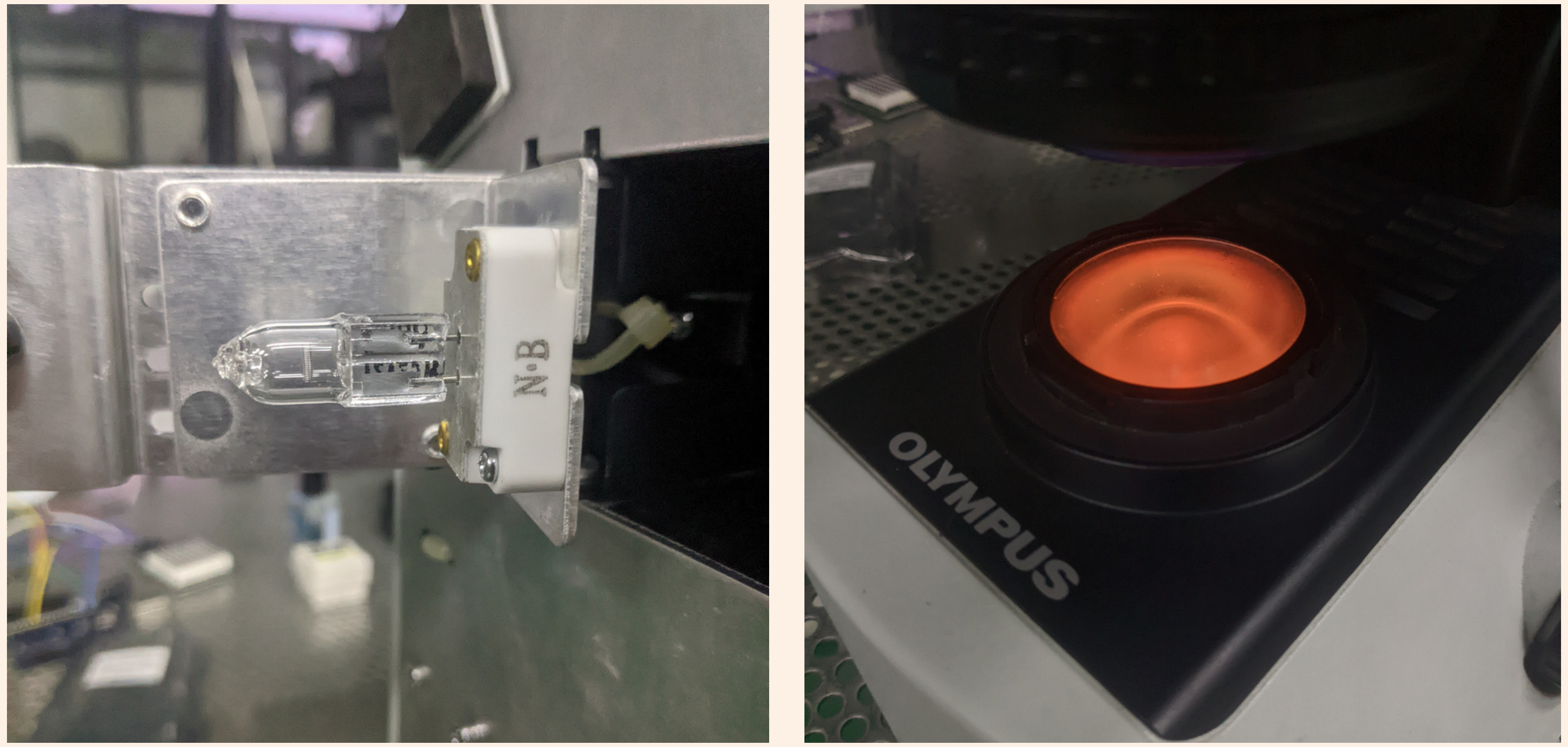
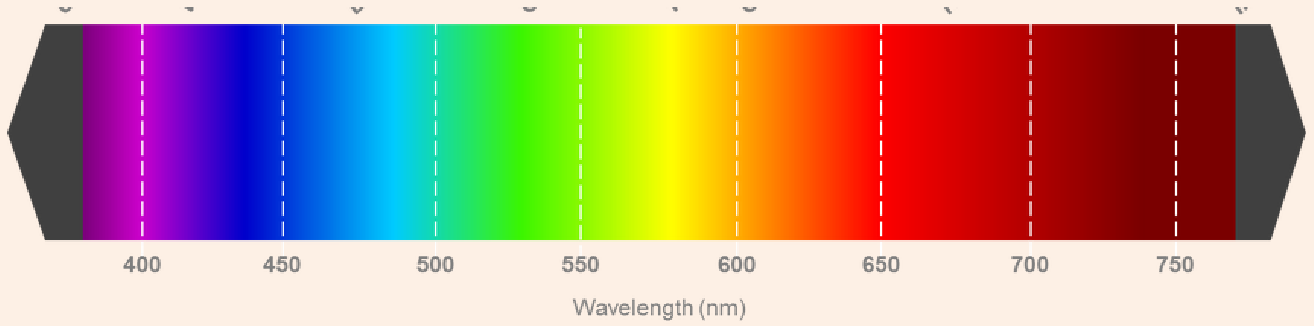


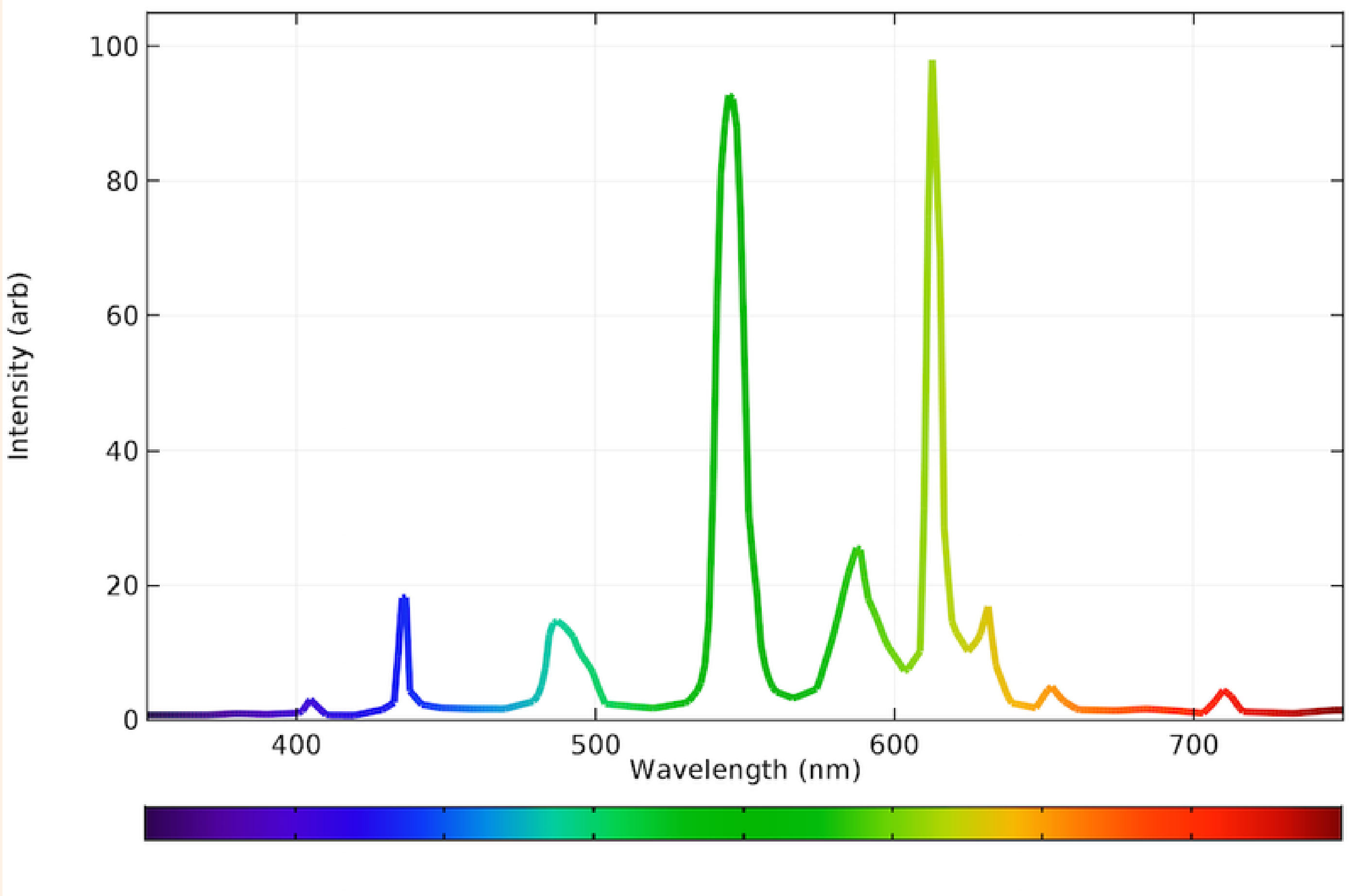
Figure 7. Halogen Bulb

Appears reddish.



RESULTS & ANALYSIS

01 LIGHT SOURCES: FLUORESCENT LIGHT



https://www.comsol.com/blogs/calculating-the-emission-spectra-from-common-light-sources

Figure 8. Fluorescent light emission spectra

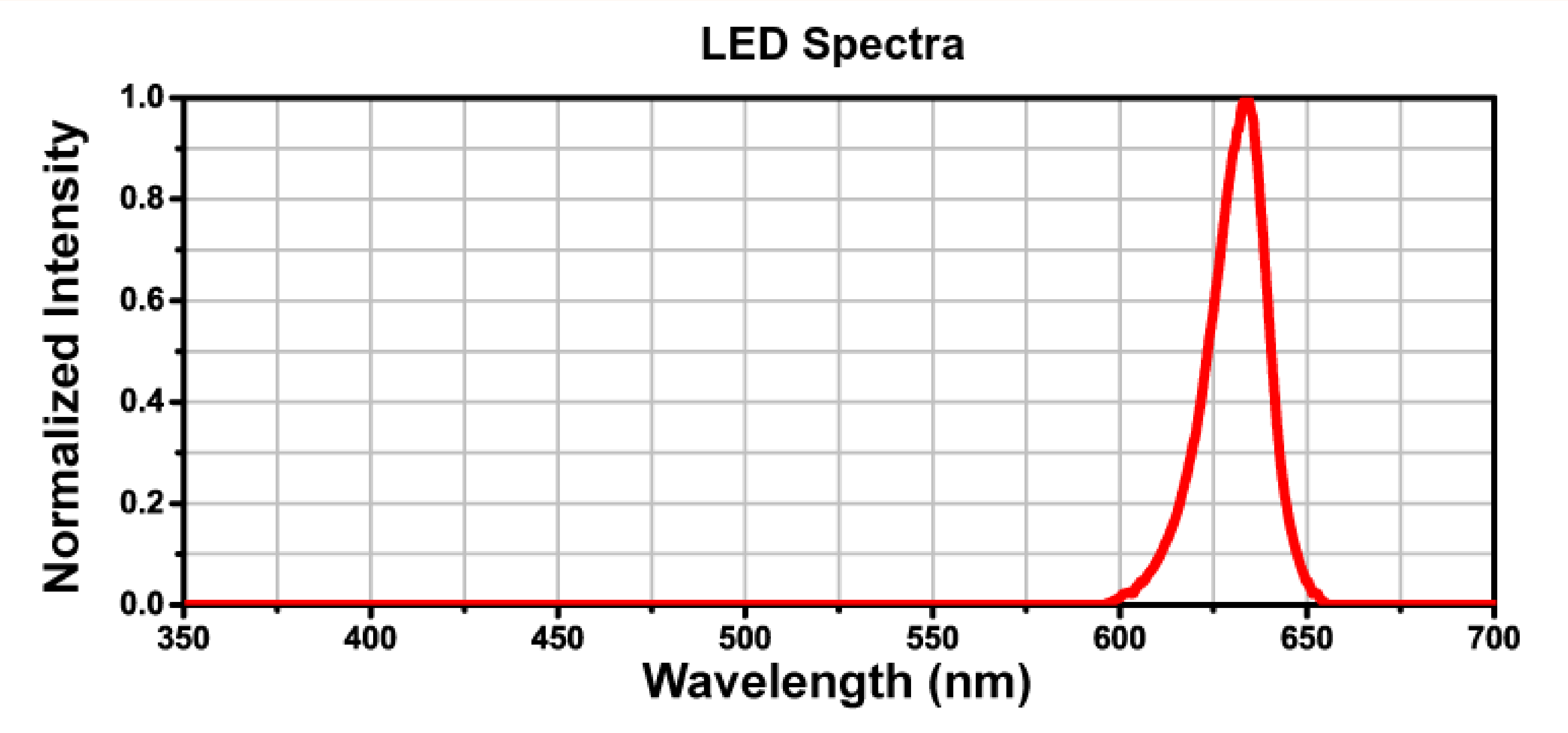
The two phospor emission peaks combine to appear white.

Figure 9. Fluorescent Light

Appears neutral white.

RESULTS & ANALYSIS

01 LIGHT SOURCES: LIGHT EMITTING DIODE



Source: https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=3836

Figure 10. Red LED emission spectra

Purely red emission.

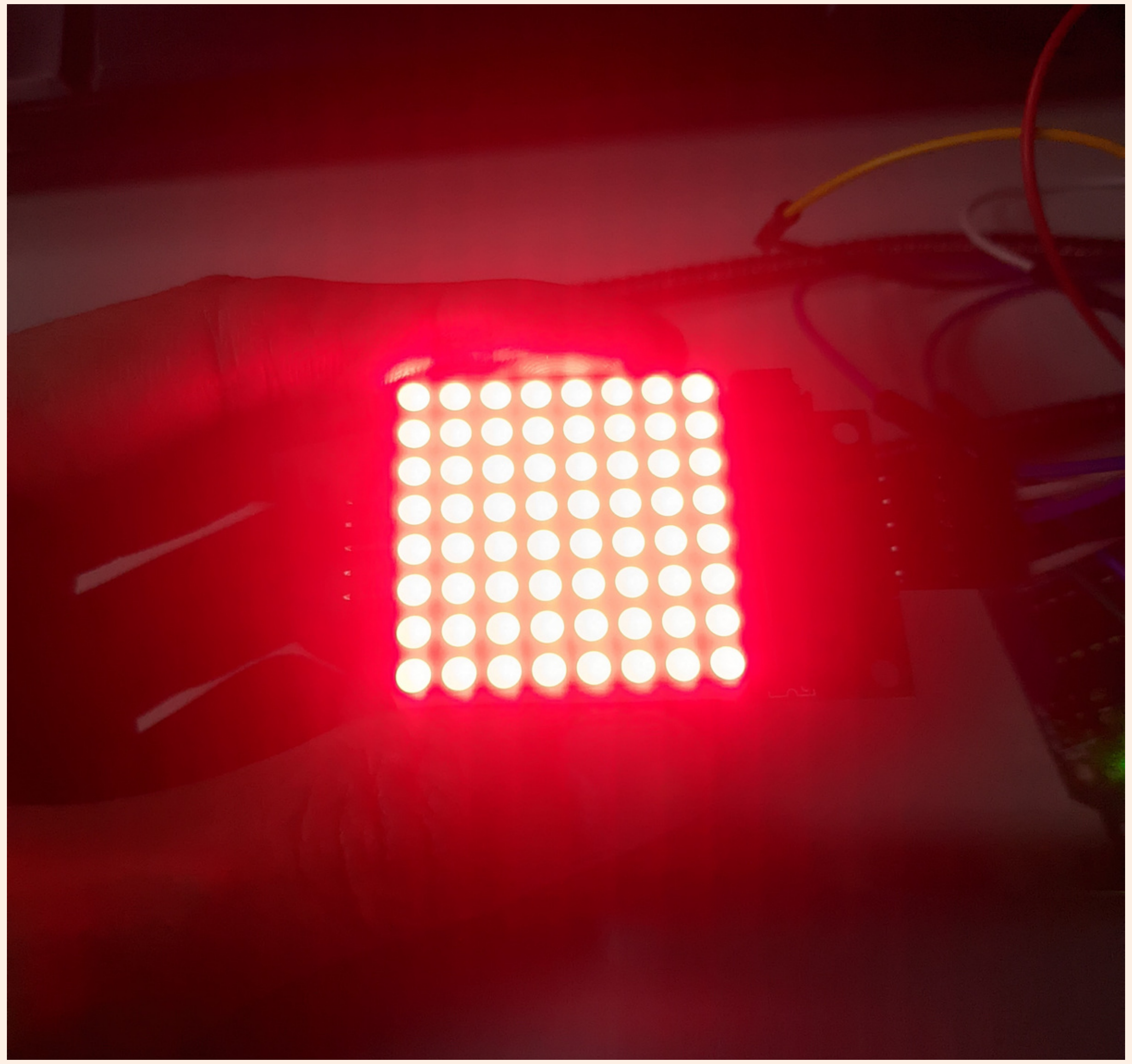


Figure 11. Red LED Light

RESULTS & ANALYSIS

01 LIGHT SOURCES

Shown on the right is the obtained radiation spectrum from a blackbody at temperature (T) derived from Planck's Law

$$B(\lambda, T) = \frac{2hc^2}{\lambda^5(\exp(hc/\lambda kT) - 1}$$

Here it shows light emitted from higher temperatures ~5000 K are very intense compared to lower temperatures ~1000K.

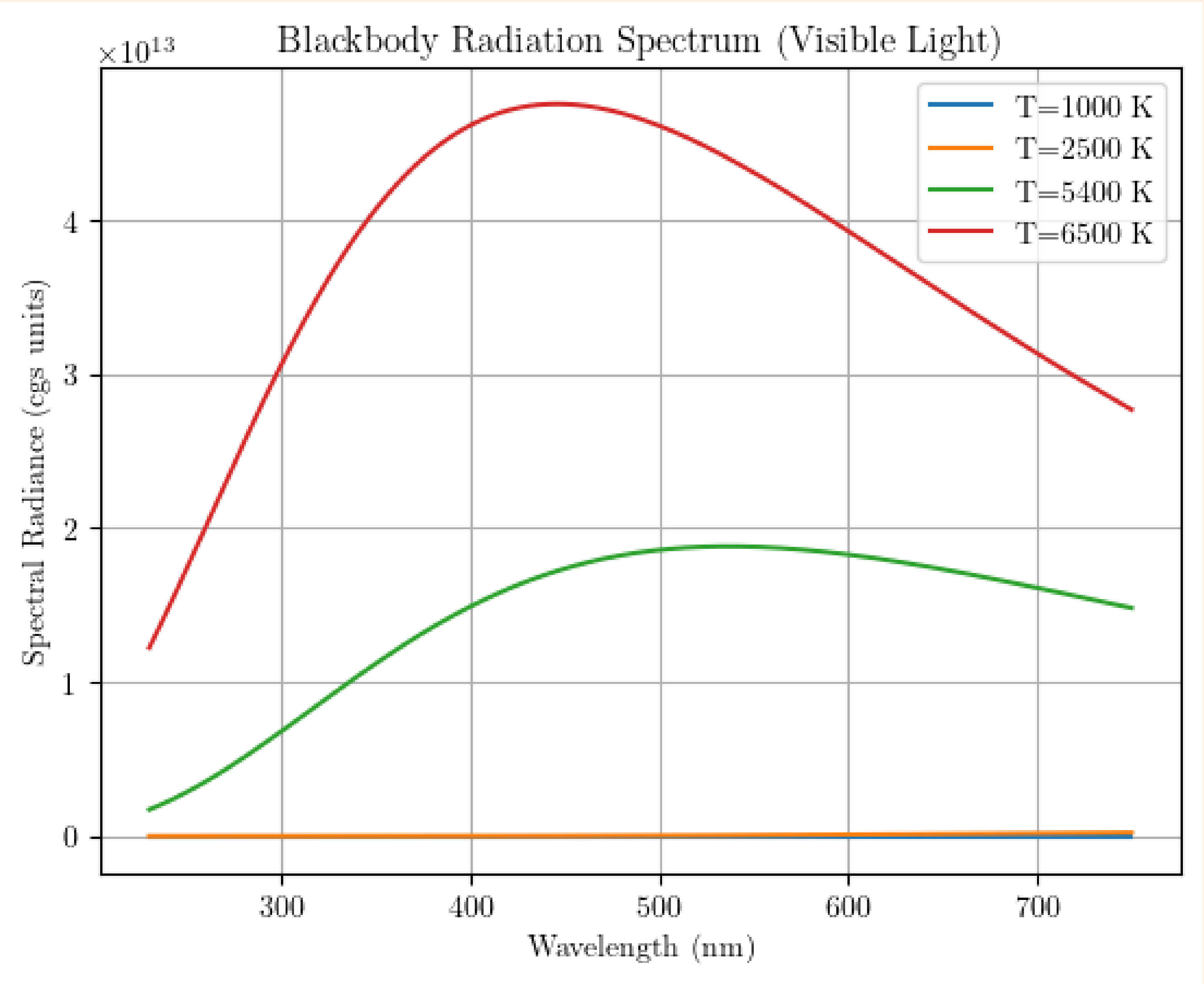


Figure 12. Blackbody radiation spectra for different temperatures, T

RESULTS & ANALYSIS

01 LIGHT SOURCES

Upon normalizing the radiation spectra for temperatures: 1000K, 2500K, 5400K, 6500K such that the **relative power** is 100 at 560 nm, we obtain the following graphs in Figure 13.

Here we can infer the **high power wavelengths** as the **dominant color** that would be perceived where **lower temperatures** appear more **red** while **higher temperatures** appear more **blue**. This is the basis of color temperature of common light sources, as shown in Figure 13.

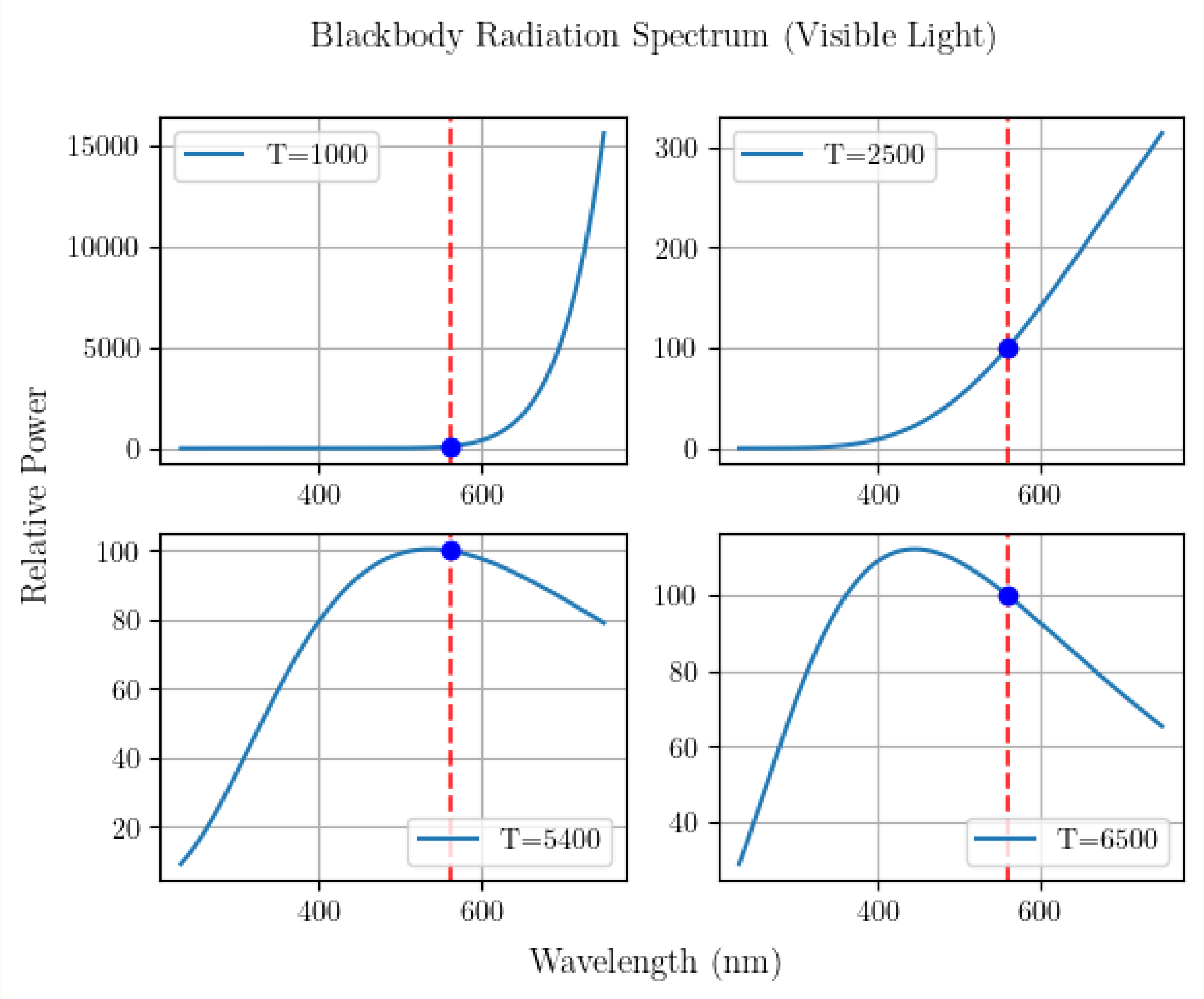


Figure 13. Relative power of blackbody sources a various temperatures, T

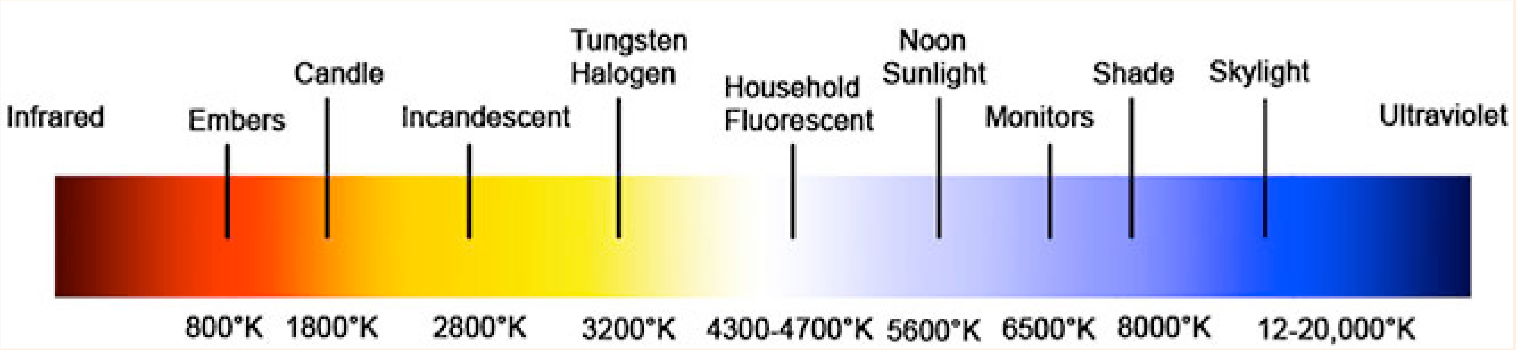
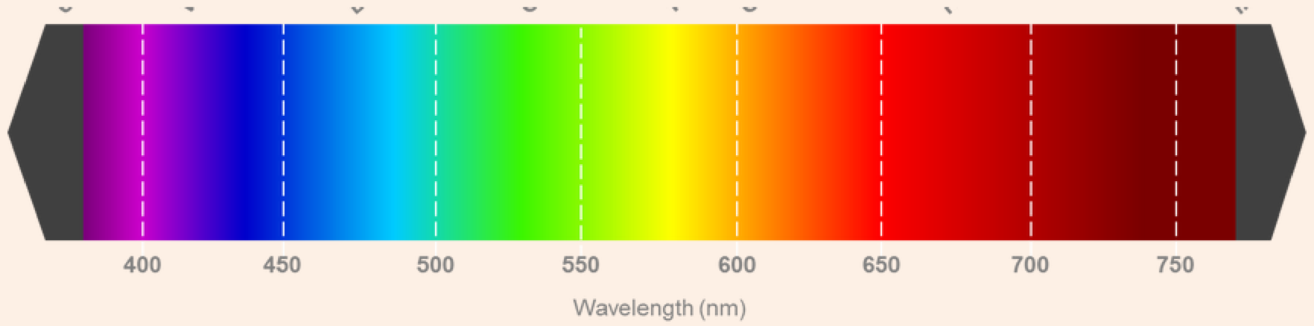


Figure 14. Color Temperature



RESULTS & ANALYSIS

02 SURFACES: REFLECTION

Moving on to light-matter interaction. Light can suddenly change direction when it collides with a boundary or surface. This phenomenon is called reflection. We can see reflections in our day to day lives. The most common examples are when we look at mirrors, shiny silverware, calm water, and waxy surfaces.

The direction at which light is reflected is described by the law of reflection. This law states that the angle of incidence is equal to the angle of reflection [1].

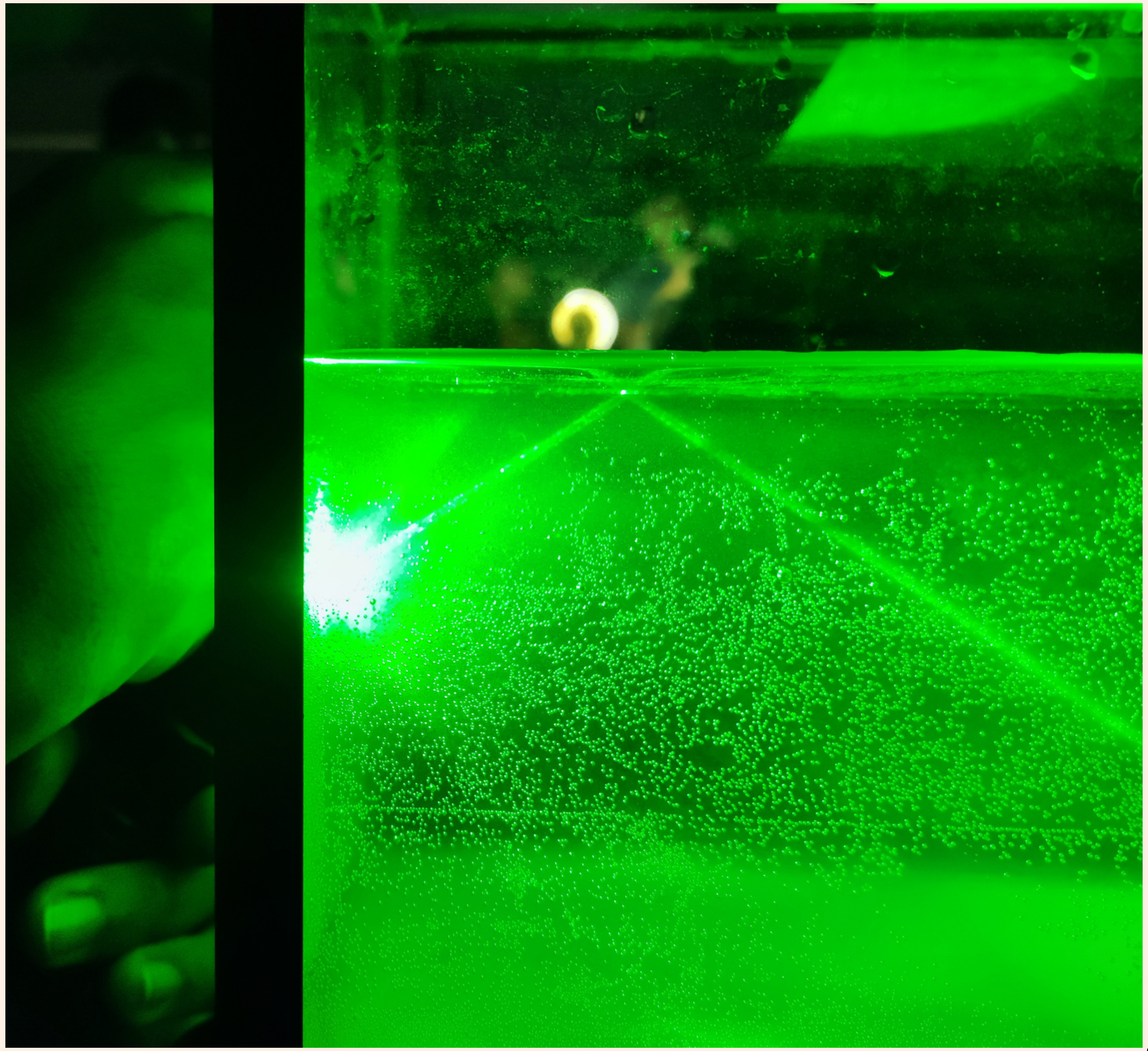


Figure 15. Total internal reflection in an aquarium.

RESULTS & ANALYSIS

02 SURFACES: REFRACTION

When light changes medium, it undergoes a phenomenon called refraction. Refraction refers to the bending of light as it is transmitted from one medium to another. The degree and direction in which the light is bent depends on the second medium's refractive index. If the second medium's refractive index is larger than first medium's, then the light bends towards the interface's normal. If the second medium's refractive index is smaller, then the light bends away from the normal [2].

The general relationship between the incident and transmitted angles are given by Snell's law [2].

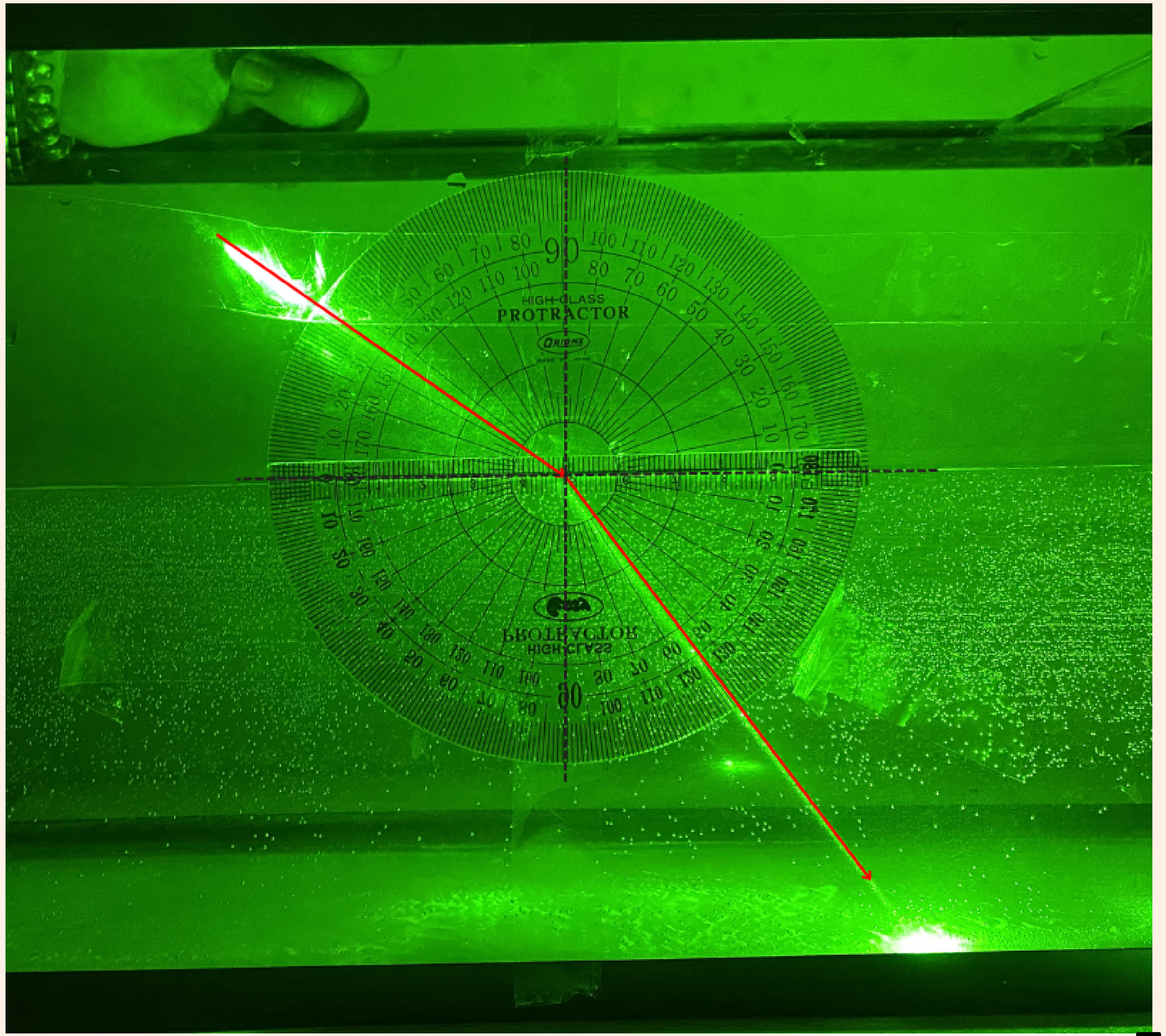


Figure 16. Refraction in an aquarium.

RESULTS & ANALYSIS

02 SURFACES: DIFFRACTION

By letting light pass through an aperture or grating, the wave nature of light will allow it to bend around the corners. This “bending” around the corners is formally called diffraction [3].

As seen in the pictures on the right, the diffraction of white light can decompose it into its constituent colors. This is because the angle of diffraction is dependent on the wavelength, Red has the longest wavelength, so it is diffracted the most. On the other hand, violet has the shortest wavelength so it is diffracted the least [3].

Figure 17. Diffraction of white light by a diffraction grating.

RESULTS & ANALYSIS

02 SURFACES: RAYLEIGH SCATTERING

Rayleigh scattering occurs when light is scattered by particles with a diameter of less than 1/10 of the incident light's wavelength. Blue light, having a small wavelength, is scattered the most. While red light, having a long wavelength, is scattered the least. This is the main reason why the sky appears blue while the sunlight that reaches the ground appears yellow or orange [4].

An example of Rayleigh scattering can be seen on the picture on the right. The moon in the center looks bluish, but as you go further out, the light appears reddish. This is because the short wavelengths were scattered first, allowing the longer wavelengths to penetrate the clouds farther [4].

Figure 18. Rayleigh scattering caused by clouds

RESULTS & ANALYSIS

02 SURFACES: MIE SCATTERING

Mie scattering is caused when light hits a particle whose diameter is larger than or similar to the wavelength of the incident light. This type of scattering is what gives the clouds their white appearance [5].

In the images on the right, it shows smoke with and without water vapor. Without water vapor, the smoke appears bluish. This is because there are no large particles to exhibit Mie scattering. But for the smoke with water vapor, the large water molecules scatter the white randomly in all direction. Thus giving it its white appearance.

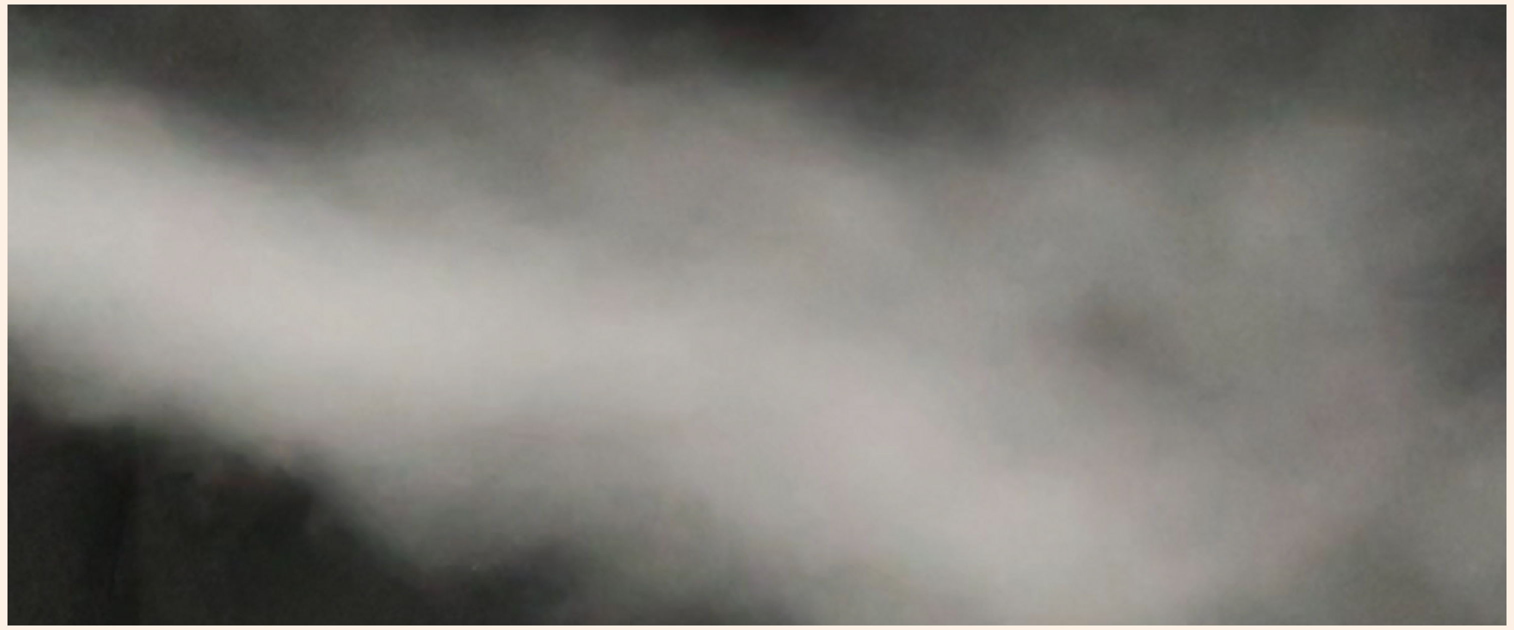


Figure 19. Smoke with water vapor

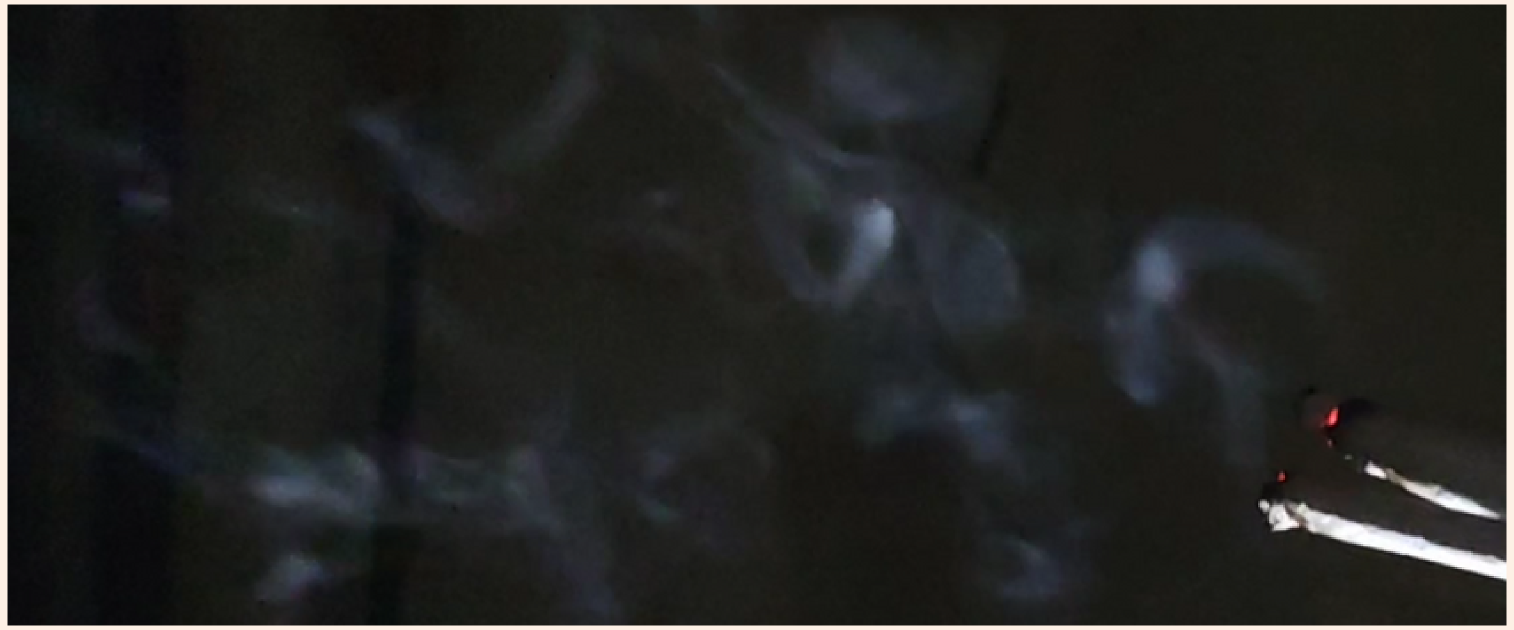


Figure 20. Smoke without water vapor

RESULTS & ANALYSIS

02 SURFACES: TYNDALL EFFECT

The main reason why we see rays of light is because of the Tyndall effect. The Tyndall effect is a type of scattering caused by colloidal dispersion [6].

For the picture on the right, we can see rays of light coming from the clouds. The rays are formed because the photons collide with dust and water particles suspended in the air. These collisions cause the light to be scattered in random directions, thus forming the light rays.

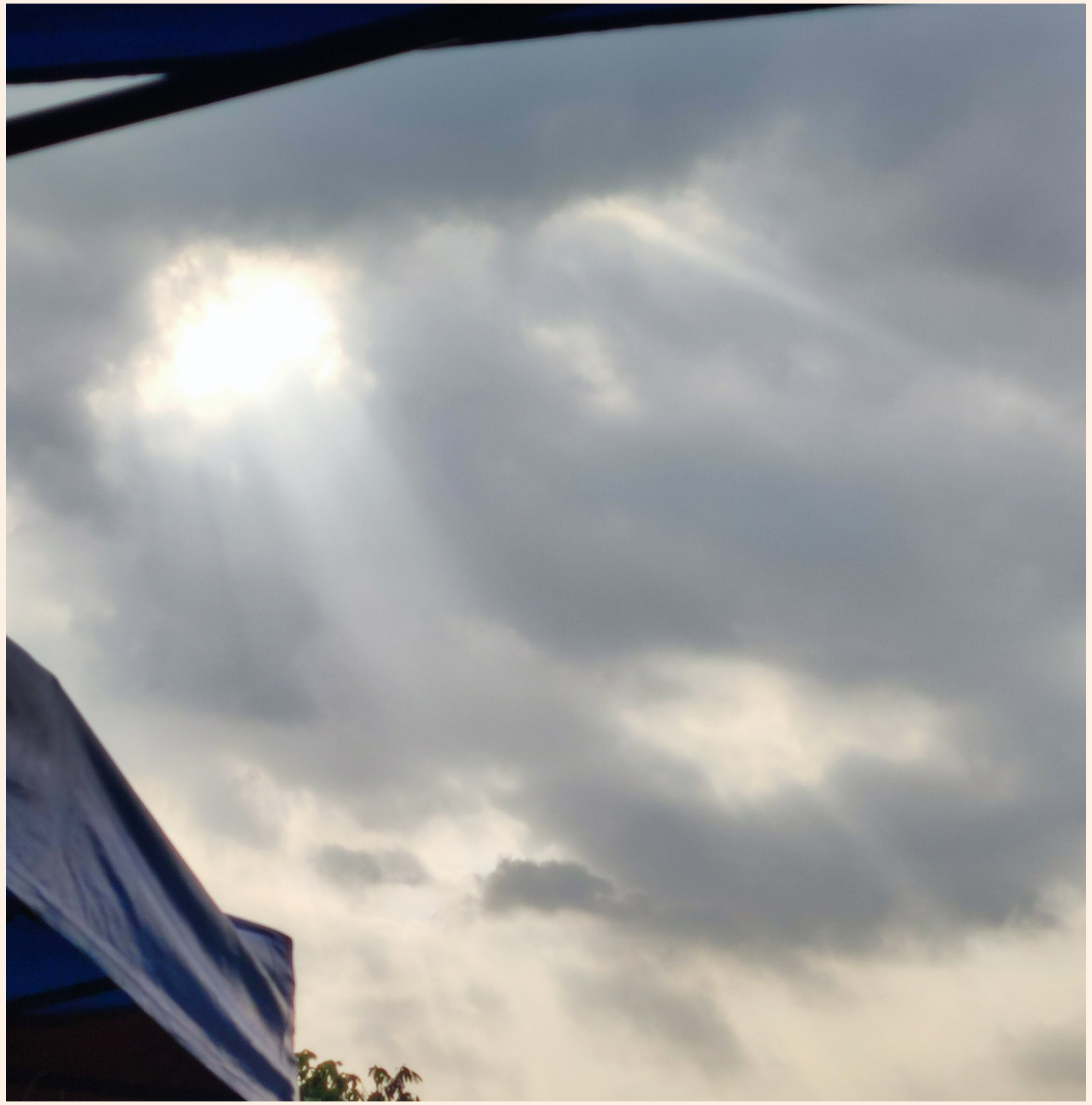


Figure 21. Visible light rays “piercing” through the clouds. The rays can be seen because of the Tyndall effect.

RESULTS & ANALYSIS

03.1 NEAR POINT

Table 1. Near point measurements of the left and right eye of each member and the corresponding eye condition.

Name	Left Eye	Right Eye	Condition
Jonabel	11.5 cm	10 cm	Nearsighted
Nicholas	17 cm	16 cm	Nearsighted
Johnenn	13 cm	11.5 cm	Nearsighted
Julian	13 cm	10.5 cm	Nearsighted

Table 1 shows the near point measurements obtained for each member and their corresponding eye condition. As shown, all the members exhibit nearsightedness or myopia because the values obtained are less than the normal value of 25cm.

Nearsightedness is a type of refractive error which happens when there is an inaccurate focusing of light in the eye. It is actually common in adolescents, and can start to develop in early childhood. The usual factors contributing to this condition is prolonged screen time and close-up activities like reading and genetics [7].

RESULTS & ANALYSIS

03.2 SCOTOPIC & PHOTOPIC VISION

Table 2. Colors that each member first saw after closing their eyes for 5 minutes.

Name	Color
Jonabel	Yellow
Nicholas	Yellow
Johnenn	Yellow
Julian	Red

Table 2 shows the color that each member first saw as they opened their eyes after closing them for 5 minutes. As observed, most have seen yellow first. This is in contrast with the concept of the Purkinje effect.

The Purkinje effect states that as light intensity decreases, the eyes perceive the intensity of red objects to fade faster than blue objects with the same intensity when subjected to a dark environment. This is due to the rod luminosity scale prevailing over the cones as darkness increases [8]. In the darkness, we use our scotopic vision. During the day, however, we use our photopic vision when cones are excited more.

The observation made in this experiment being different from what should have been observed may be due to the setup not being too dark for the eyes to acclimate.

RESULTS & ANALYSIS

04 CAMERAS

Table 3. Phone cameras and their corresponding specifications and technical reviews.

Camera	Specs	Links to Review
Xiaomi Pocophone F1	Dual Main Camera: Main: 12MP, f/1.9 Second: 5MP f/2.0 Selfie: 20MP f/2.0	The rear camera performs well, delivering decent still-image results for exposure, color, and noise in most conditions.
Xiaomi Mi 11 Lite	Triple Main Camera Wide: 64MP, f/1.8 Ultrawide: 8MP, f/2.2 Macro: 5MP, f/2.4 Selfie Camera: 16MP, f/2.5	Consistently accurate exposure for faces in various lighting conditions, effective noise control in low light, pleasing skin tones, and reliable preview exposure for portraits in challenging HDR scenes.

RESULTS & ANALYSIS

04 CAMERAS

Camera	Specs	Links to Review
Apple iPhone 13 Mini	Dual 12MP camera system (Main and Ultra Wide) Main: 12MP, f/1.6 aperture Ultra Wide: 12MP, f/2.4 aperture Selfie Camera: 12MP f/2.2 aperture	Precise and consistent target exposure, pleasing colors, reliable white balance, and skin tones in diverse lighting, coupled with swift, accurate, and consistent autofocus, delivering good detail in both daylight and indoor conditions. Larger sensor and optics in iPhone 12 Pro Max incorporated into the small 13 Mini
Xiaomi Redmi Note 11	Quad main camera (Main, Ultra-Wide, Macro, Depth Camera) Main: 50MP, f/1.8 Ultra Wide: 8MP, f/2.2 Macro: 2MP, f/2.4 Depth: 2MP, f/2.4 Selfie Camera: 13MP, f/2.4	Xiaomi's global Redmi Note 11's flagship camera specs at a mid-range price point provides fairly standard budget camera setup.

RESULTS & ANALYSIS

05 VISUAL ACUITY

Table 4. Angle measurement for each member. L is the eye-wall distance, and x is the fixation point - last letter distance.

Name	L	x	Angle
Jonabel	27.5 cm	1.1 cm	2.29°
Nicholas	30 cm	1 cm	1.91°
Johnenn	39 cm	1.9 cm	2.79°
Julian	31.5 cm	1.1 cm	1.99°

Table 4 shows the angle obtained for each member. As observed, the range of the angles is 1.9 to 2.8 degrees. This angle represents the angle of the fovea which is a depression at the center of the retina that provides the sharpest vision.

The maximum visual acuity is provided by the fovea which is approximately 1.5mm in diameter. Because it does not contain any blood vessels, it enables humans to see with a sharp vision. Everyday activities like reading, writing, and looking at objects up-close are all enabled because of the fovea. The fovea angle varies among individuals due to our anatomical variations [9].

CONCLUSIONS

1. Different light sources emit widely varying spectra with some having **multiple broad wavelengths**, while some can have **specific narrow bands**. The temperatures of a blackbody radiator were shown to have correlated color signatures **(reddish/bluish)** that serve as a basis for color temperatures for typical lights.

2. We have successfully shown and discussed images of several **light-matter interactions**. These interactions were: **reflection**, **refraction**, **diffraction**, **Rayleigh scattering**, **Mie scattering**, and **Tyndall effect**.

3.1. The near point measurements of the members are **below** the normal value making them **nearsighted**. This condition is common in adolescents and is due to prolonged screen time and close-up activities.

CONCLUSIONS

3.2. **Yellow** is the common color seen first, which contrasts with the concept of the **Purkinje effect.** This may be due to the dark enclosure not being too dark for the eyes to acclimate.

4.The camera specifications of are of varying range with the highest being **64MP** and the lowest being **2MP.**

5. The **fovea angle** range observed is **1.9 to 2.8 degrees**. This angle varies among individuals due to anatomical variations.

REFLECTION

We effectively accomplished the objectives of this activity through teamwork. Tasks were evenly distributed, ensuring each member had a role. This activity provided valuable insights into light-matter interaction and offered fascinating discoveries about the intricate workings of the human eye.

Engaging in this activity was both enjoyable and enlightening, involving a series of experiments that allowed us to explore aspects of our eye conditions. Some participants even became aware of the need for eye check-ups! Overall, this experience proved to be rewarding for all involved.

GROUP GRADE

CRITERIA	perfect score	our score
Technical correctness	30	30
Quality of presentation	30	30
Reflection	30	30
Ownership	10	10
TOTAL	100	100

We were able to achieve all the objectives of this activity. Each of the members had a role to play in accomplishing the task. Overall, we give credit to ourselves for obtaining good results and being able to finish the activity on time.

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