Lesson Title	15. Physics of Color Vision
Lesson Designer	Nicole Granucci
Standards	☐ CCSS ☑ NGSS ☐ ASCA ☐ Other PS4.B: Electromagnetic Radiation Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. (HS-PS4-3) When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. (HS-PS4-4)
Learning Objectives	Students will make various colors using the three additive primary colors of light, identify the characteristics that make a color appear dark or light, and explain how the brain sees different colors.

Timeline	Duration
Day 1: laboratory simulation	90 minutes

Teaching Strategies/Student Actions	Monitoring
Students can be given the notes sheet to read for information from, or the instructor can just use the notes as a basis for the necessary information. The laboratory activity contains detailed instructions for students to conduct independently.	• Teacher monitors student progress • Teacher facilitates discussion • Teacher questioning

Product Description	
Evaluation	Student analysis of questions embedded in lab

Resources and Materials	Additional Notes
Web resources: • PHET - Color and Vision Simulation https://phet.colorado.edu/sims/html/color-vision/latest/color-vision_en.html • Color and Vision - https://www.physicsclassroom.com/class/light/Lesson-2/Visible-Light-and-the-Eye-s-Response • Color Addition - https://www.physicsclassroom.com/class/light/Lesson-2/Color-Addition	

Physics of Color Vision Learning Task

Introduction

Visible light is a wave that is part of the electromagnetic spectrum. The wavelength of the light wave denotes the color and the amplitude denotes the brightness of a light wave. Figure 1 shows the colors and their corresponding wavelengths. The main colors of the rainbow: red, orange, yellow, green, blue and violet can be characterized by the wavelengths. Notice that other colors are missing, such as white, magenta and teal.

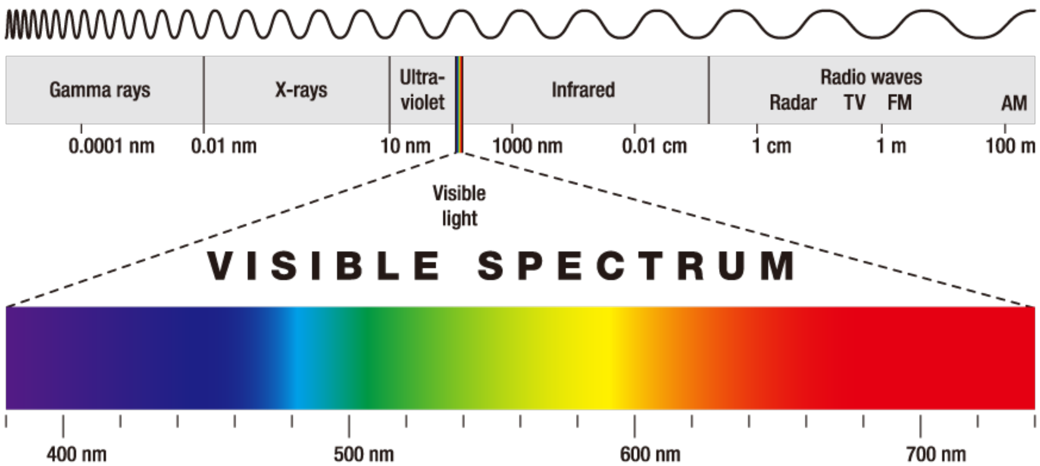
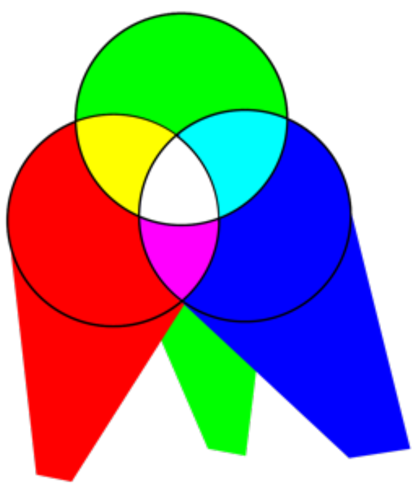


Figure 1 – The electromagnetic spectrum. Visible light is a very small part of the spectrum.
Photo credit: https://www.benq.com/en-au/knowledge-center/knowledge/what-is-accurate-color.html

The question then is how do we see all the colors? The way we see colors has to do with the additive color theory of light. There are three primary colors of light: red, green and blue. When two primary colors are combined, they make the secondary colors: yellow, magenta and cyan. When all three colors are combined, they make white. This is contradictory to your understanding of colors learned in elementary school. This is because that type of color mixing uses a different principle of color addition called pigments and actual work with color subtraction.



Additive color mixing with red, green and blue additive primary colors.

Figure 2 - Photo Credit - http://hyperphysics.phy-astr.gsu.edu/hbase/vision/addcol.html

Our eyes have three cone receptors that take in specific wavelengths of light: red, blue and green. The intensity of each of these colors (brightness) levels change what we see and interpret as color. In this lab, you will learn how we interpret different colors based on different intensity levels. Furthermore, you will explore how certain materials can absorb light and therefore be interpreted differently as well.

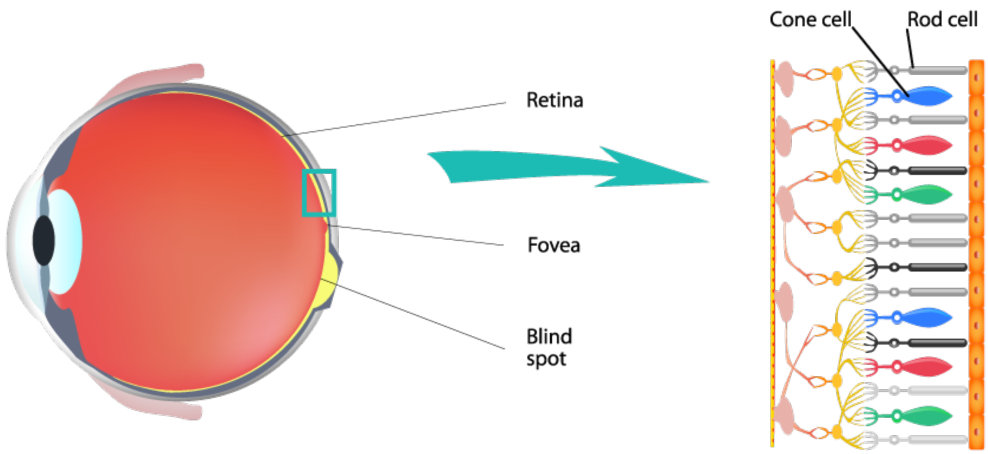


Figure 3 - The eye anatomy. The fovea is the most sensitive part of the eye with the majority of the rods and cones there. The cones are sensitive to red, green and blue and thus gives the brain the ability to interpret different colors. Photo credit: https://www.benq.com/en-au/knowledge-center/knowledge/what-is-accurate-color.html

Procedure and Questions

1. Open the link to Phet Color and Vision https://phet.colorado.edu/sims/html/color-vision/latest/color-vision_en.html
2. Select RGB Bulbs.
3. There should be three flashlights that represent the three primary additive colors. **What are the three primary colors?**
4. All of the sliders for the colors should be in the "off" position, where there is no light transmitted to the eyes. The thought-bubble above the person represents what the person interprets when light hits their eyes. **What color does the person "see" when no light hits their eyes?**
5. Turn the Red slider all the up to 100%. **What color does the person see?**
6. Adjust the red slider to 50%. **What color does the person see?**
7. Adjust the red slider to 25%. **What color does the person see?**
8. **What happened to the color as you bring the slider closer to 0%?**
9. Adjust the red slider up and down. Observe the "red dots" as you do this. These dots are the photons of red light. When more photons hit the eyes of the observer, the color appears _________ (brighter/darker).
10. Return the red slide all the way back down to zero. Turn the Green slider all the up to 100%. **What color does the person see?**
11. Adjust the green slider to 50%. **What color does the person see?**
12. Adjust the green slider to 25%. **What color does the person see?**
13. **What happened to the color as you bring the slider closer to 0%?**
14. Return the green slider all the way back down to zero. Turn the Blue slider all the up to 100%. **What color does the person see?**
15. **Prediction: If you wanted to make navy (dark blue) what percentage of the slider should you place the blue slide?**
16. Test your prediction and note where the slider was placed to generate this color.
17. Summarize your understanding of the intensity of the color in terms of brightness.
18. **Prediction: If you mix 100% red and 100% green, what color would the person interpret this as?**
19. Test your prediction and give the actual color when mixed. **Is it what you expected?**
20. **Prediction: If you mix 100% red and 50% green, what color would the person interpret this as?**
21. Test your prediction and give the actual color when mixed**. Is it what you expected?**
22. **Prediction: If you mix 50% red and 100% green, what color would the person interpret this as?**
23. Test your prediction and give the actual color when mixed**. Is it what you expected?**
24. **Prediction: If you mix 100% red and 100% blue, what color would the person interpret this as?**
25. Test your prediction and give the actual color when mixed. **Is it what you expected?**

26. **Prediction: If you mix 100% red and 50% blue, what color would the person interpret this as?**
27. Test your prediction and give the actual color when mixed**. Is it what you expected?**
28. **Prediction: If you mix 50% red and 100% blue, what color would the person interpret this as?**
29. **Prediction: If you mix 100% green and 100% blue, what color would the person interpret this as?**
30. Test your prediction and give the actual color when mixed. Is **it what you expected?**
31. **Prediction: If you mix 100% green and 50% blue, what color would the person interpret this as?**
32. Test your prediction and give the actual color when mixed. **Is it what you expected?**
33. **Prediction: If you mix 50% green and 100% blue, what color would the person interpret this as?**
34. Test your prediction and give the actual color when mixed**. Is it what you expected?**
35. **Prediction: If you mix 100% green, 100% red and 100% blue, what color would the person interpret this as?**
36. Test your prediction and give the actual color when mixed. **Is it what you expected?**
37. Summarize your findings as you mixed the three different primary colors with different intensities of light.

Make the following colors. Give the intensities of red, green and blue as percentages.

Color	Color Name	Red Intensity	Green Intensity	Blue Intensity
	**Gray**			
	Mint Green			
	Periwinkle			
	**Maroon**			
	Light pink			
	**Forest green**			
	**Honey**			

Analysis Questions

1. According to the image in Figure 1, the only colors that are produced by electromagnetic waves are the standard rainbow colors - red, orange, yellow, green, blue, purple. If those are produced by electromagnetic waves, then why can we see colors like mint green and magenta? How can we see absent colors in the spectrum? Explain.

2. After using this simulation, how do people see different colors? How does the brain interpret different intensities of red, green and blue?