Module Theme | Science & Engineering
Pacing | 1 class period (~45 minutes)

Background Needed | Basic understanding of remotely operated vehicles
Assessment | Student worksheet and student participation in discussions

Overview

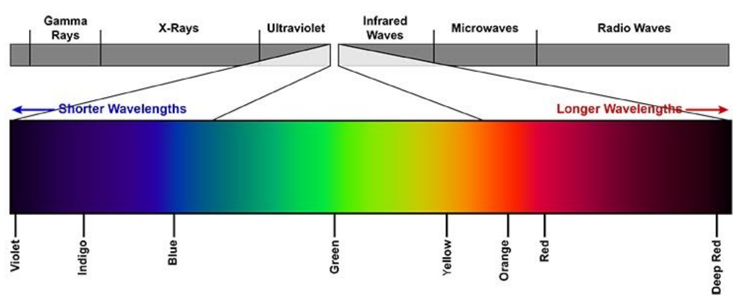
Five activity stations and demonstrations guide students through different examples of light refraction and ask follow-up questions to engage their analysis skills.

Sunlight rarely travels more than 200 meters (656 feet) deep into the ocean. Vast unexplored regions of the ocean are perpetually dark. Bringing light deep into the ocean introduces challenges, but also the chance to make many discoveries.

Exploration Vessel (E/V) *Nautilus* uses ROVs (remotely operated vehicles) to explore the world's ocean mostly between 1,000 - 6,000 meters. ROVs are equipped with high-definition cameras which send high-resolution video up a fiber-optic cable to the control room on the ship. The same video of discoveries is transmitted via satellites to scientists and students online worldwide.

Without lights, it would be impossible for ROV cameras to see the seafloor habitats and creatures. Because light travels differently through water than through air, and colors of light behave differently, bringing light underwater introduces challenges. Dive depth, presence or absence of particles in the water, and lighting configuration impact the apparent colors cameras record. Calibrating video cameras is essential to capture the best scientific data quality.

Visible light is only a small portion of the full electromagnetic spectrum. Light is a wave of energy made up of different wavelengths. Visible light is a combination of wavelengths represented by colors of the rainbow.



In air, all wavelengths/colors of visible light travel equally well. In water, different colors of light are absorbed and scattered at descending depths. Long wavelengths, like red, are absorbed more quickly than shorter wavelengths like blue. Without supplemented light, the world beneath the waves can appear dull. Red fish appear nearly black at 20 meters (65.6 feet). Without lights, ROVs could only pick up certain colors of light as they descend until losing all available light.

Explore the phenomena of colored light, phased absorption of different wavelengths, and other impacts to light underwater with the following five activities. (Image credit: National Weather Service)

Objectives & Learning Outcomes

Students will:

- understand the importance of ROVs in *Nautilus*' mission of ocean exploration.
- discuss why equipping ROVs with supplemented white light is necessary when recording video or images of marine organisms and habitats.
- understand refraction and describe how refraction varies throughout the ocean depths

Additional Background Resources

- Watch color loss in water from 0-155 feet https://www.youtube.com/watch?v=AAJjdA6b4Ts
- Light penetration across different water depths graphic © 2005 Brooks/Cole - Thomson
- Video clips from E/V *Nautilus* expedition to Baker and Howland Islands. Interview with Video Engineer Marley - Light Balancing Part 1 and Interview with Video Engineer Marley - Light Balancing Part 2

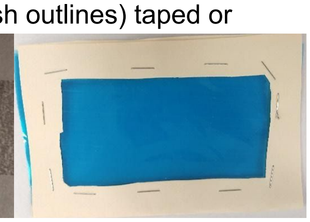
Links to Next Generations Science Standards

- MS-PS4-2 - Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
- HS-PS4-4 - Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

Materials

- Student worksheet per student
- Activity 1 (per group)
  - 3 small glass beakers & 3 pennies
- Activity 2 (one class set)
  - Large glass jar
  - Blank pyrex beaker small enough to fit into the large glass jar (Note: This can be purchased and is often sold as "The Disappearing Beaker.")
  - Cooking oil enough to completely submerge the pyrex beaker when placed in the large glass jar
- Activity 3 (one class set)
  - Green laser pointer & red laser pointer
  - Colored duct tape - at min white, green, neon (not blue or purple)
  - White foam board with colored duct tape strips (in the order listed on activity sheet) *You can change based on available colors of tape. However, the first stripe should be white, the second stripe green, and the last set must be neon, but not neon blue or purple.

- Activity 4 (one class set)
  - Green laser pointer & red laser pointer
  - Small fish tank – 10 gallons
  - ~2 cups (400 mL) of cold, whole milk
- Activity 5 (per group)
  - Black construction paper card with construction paper patches (or fish outlines) taped or glued on. (purple, blue, green, red, orange, and yellow)
  - Blue filter - Fold a file folder in half. Cut a window. Seal in four layers of blue cellophane.

Vocabulary

- **Absorption** of light occurs when water takes in energy from light waves
- **Electromagnetic spectrum** is the range of wavelengths or frequencies light arranged from lowest energy and longest wavelength to highest energy and shortest wavelength, radio waves, microwaves, infrared radiation, visible light (red, orange, yellow, green, blue, indigo, and violet), ultraviolet radiation, x-rays, and gamma rays.
- **Fluorescence** occurs when an object absorbs light of short-wavelength and emits light of longer wavelength.
- **Reflection** is the bouncing back of light or sound waves from a surface.
- **Refraction** is the bending of light or other wave as it travels at an angle from one medium, or substance, to another with a different density.
- **ROV (Remotely Operated Vehicle)** is a tethered underwater mobile vehicle.
- **Scattering** occurs when light is diffused through a medium.

Educator Procedure

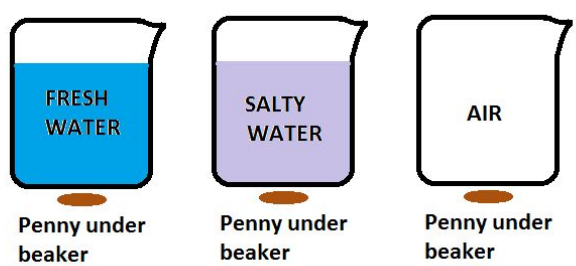
Opening

Ocean exploration is a complicated endeavor requiring advanced tools and technology. The Corps of Exploration's E/V *Nautilus,* is one of only two dedicated ships of exploration in the world. The team uses a multibeam sonar system to map unknown areas of the seafloor. After data is analyzed and targets are chosen, they send remotely operated vehicles (ROVs) to explore the seafloor collecting video footage and a variety of physical samples. For most missions, *Nautilus* uses two ROVs, *Argus* and *Hercules*. Video from *Hercules*' high-definition camera is streamed up a fiber-optic cable connected to *Argus*, from *Argus* to the control van on the ship, then through a satellite link out to the world online.

Share highlight video clips recorded by *Nautilus*' ROVs with students via the Nautilus Live website gallery or YouTube channel. Ask students to come up with reasons why *Hercules* and *Argus* have powerful white lights. Ask for several different reasons to challenge students to think beyond just making sure ROV pilots can see where they are going. Ask the students how they think the video recorded by *Hercules* and *Argus* might be different if it relied on natural lighting.

Activity 1: Group students into groups of three to four students.

1. Place a penny under a beaker of 80mL fresh water, a beaker of 80mL salty water, and an empty beaker. Line up beakers in a straight line like in the picture.



2. While standing, look down at all of the pennies under the three different beakers so that you see them all at the same time.
3. Students should slowly lower themselves to a crouching position while looking at the pennies. Students will observe the pennies slowly disappearing. Record observations on the worksheet.

Teacher notes: The penny under the air will not disappear. The saltwater penny will disappear slightly faster than the freshwater. The different densities of these mediums refract light at different angles. Tie this to students' experiences of seeing their feet look distorted while standing in a shallow pool of water is a good way to introduce the idea that light traveling through ocean water will refract and change what we see ocean compared to what we would see above sea level.

Activity 2:

Before the lesson begins, set out a large glass jar filled with cooking oil and an empty Pyrex beaker inside. Pyrex's index of refraction is very similar to oil, making it very difficult to see in the jar of oil.

1. Ask students if they saw the large jar and the oil in it that has been sitting out during activity one. If they respond that they have, pull out the inner beaker. Ask how many saw the beaker in the jar the entire time. This is a generally a wow moment!

2. Explain that the light was refracted (or bent) at similar amounts when passing through the oil and the glass beaker, making it look like it disappears in the oil, just like the pennies appear to disappear under the small beakers of freshwater and saltwater in activity one.

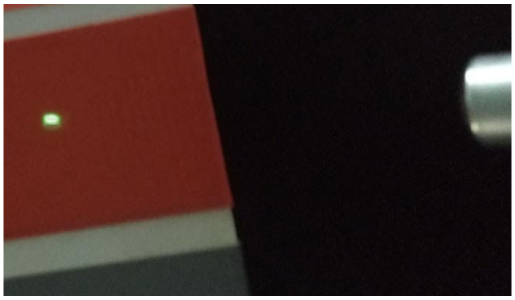
Activity 3:

Shine the green laser pointer onto the ceiling. Describe that students see a visible laser light as giving off green light because that's the color wavelength bouncing off the ceiling and then hitting their eyes. Lasers emit one wavelength of light, the ceiling reflects the same wavelength, and that's the color of light entering their eyes.

1. Ask what color students expect to see as the laser shines on each duct tape color, one at a time.

2. Try it! The dot will appear green on all the first strips of duct tape and the students will most likely begin calling out "green" quickly when asked what color of light they think will be reflected back.

3. When the laser hits a neon tape color, the laser dot changes and appears yellow-orange. Dyes used in neon duct tape colors (other than blue or purple) fluoresce (absorbing some of the laser's energy) changing the color of the visible light reflecting back to students' eyes.



Green dot

Yellow-orange dot

4. Ask students where orange and yellow are on the visible light energy spectrum compared to green. They may need a reference or to be led towards concluding orange and yellow are lower wavelengths or lower on the energy scale than green. The dot turns orange/yellow because the neon duct tape dyes absorb some energy, reflecting lower energy light (orange/yellow) to our eyes.

5. Repeat step 2 and 3 using a red laser. There will be no changes across colors.

6. Discuss these results with students. Ask why they think no change occurred. Students may need help concluding this test began with red- the lowest energy light wavelength human eyes can see.

Discuss what wavelengths of light students expect to penetrate the furthest in the ocean. Blue and green light penetrate farther than the lower energy red light.

Activity 4

Fill the fish tank with water and turn off classroom lights.

1. Shine the green and red lasers through the water. Though both travel well in water, the green will appear brighter.

- This is a good opportunity to show students **refraction.** Be careful to make sure students are not in the path of the laser light. Shine the green laser through the tank, at an angle. Point out the angle the laser light is traveling before entering the tank. Notice it is not the same angle traveled when the beam enters the water. The beam will refract again as it travels out of the tank, often ending up on the ceiling.
- Students may notice the laser light bouncing off the bottom of the tank and the surface of the water. This is an example of **internal reflection**.

2. Pour milk into one side of the tank. The milk represents solids dissolved into ocean water. Stir the water and milk to get the water evenly cloudy.

3. Hold the green laser light to the side of the tank and shine it through the cloudy water. The laser will light up all or almost all of the tank. Mark the light extent with a dry erase marker.

4. Repeat the previous step using the red laser light. The red laser will only light a small portion of the cloudy water. This illustrates for students how red light is absorbed and scattered more easily — analogously to at shallower depths — than green or blue light.

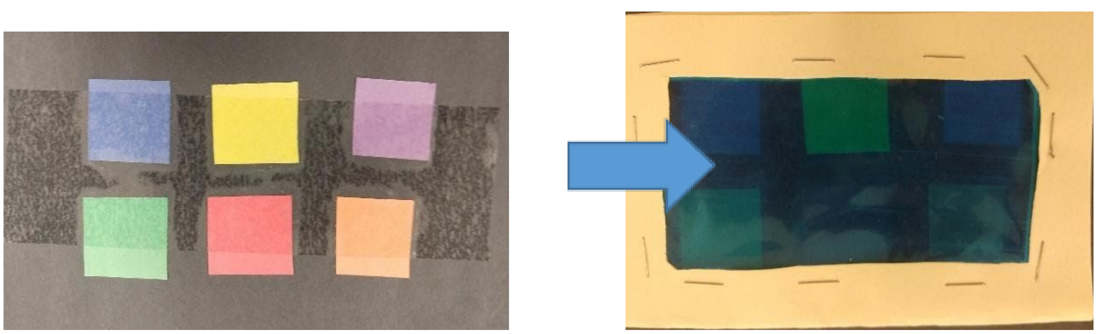
Activity 5

1. From the black color card - ask students to predict which three colors they think will blend in best with the background when viewed through the blue filter. Share out students' predictions as a class.

2. Hold the blue filter over, but not touching, each of the colored squares on black color card.

3. Looking through the blue filter, have students record the three colors they think blended best with the black background.

- *Teacher note:* Students will see red is almost black through the viewer, while the blue and green are easy to see.



4. Share student observations.

5. Prompt a discussion on what color students would prefer to be if they became a fish living in deep water. If necessary, guide the concepts learned. I.e. Because red light is lost through absorption and scattering before blue or purple light, red organisms blend into the dark black of the water column and can hide from predators and/or the prey they want to eat.

Closing

Share video clips recorded by *Nautilus*' ROVs on the Nautilus Live website or EV Nautilus YouTube.

Ask students to discuss why it is important to mount powerful lights on ROVs to explore marine habitats and the animals that live there. Discuss why organisms might look different underwater than when they are sampled and brought onboard E/V *Nautilus*. Discussions should include how refraction of light and absorption of different colors of light can change how objects appear underwater as compared to how they appear above the surface. The ability to capture high quality video data helps scientists identify species and features of the ocean floor, as well as allows audiences around the world to appreciate the wonders and beauty of our ocean.

Extensions & Adaptations

Voices in STEM | Meet Marley Parker, Video Engineer

"I am a photographer,videographer, and science writer. I specialize in helping scientists and research institutions tell stories about their efforts to explore and conserve the wonders of our natural world." Marley Parker was aboard E/V *Nautilus* exploring the Central Pacific Ocean near Baker and Howland Islands and the Johnston Atoll in summer 2019. This expedition collected basic, baseline information to support science and management decisions in U.S. marine protected areas in the central Pacific Ocean. The team conducted seafloor mapping and acquired video, biological, chemical, and geological samples in portions of the Pacific Remote Islands Marine National Monument to better understand marine habitats, biogeographic patterns, seafloor mineral distribution, and the geologic history of these areas.

Videos from E/V *Nautilus* expedition: Interview with Video Engineer Marley - Light Balancing Part 1 and Interview with Video Engineer Marley - Light Balancing Part 2. Marley explains that at the bottom of the ocean we have absolutely no light, so we have to bring our own. ROV *Hercules* has 8 different lights on the front of the vehicle. Once on the seafloor, video engineers zoom in on calibration colors on the manipulator arm. The white square helps engineers program the cameras as what a pure white slate looks like under ROV lights. The blue, green, and red bars also provide a calibration for the camera showing video engineers like Marley whether the camera looks correct for surface-light conditions.

1. Watch the two video interviews linked above. In your own words, why is Marley, and others in her same role as video engineers, so important to the exploration team of E/V *Nautilus*?

Students can give a variety of responses. Possible responses could be related to: video and images help researchers study ocean organisms and features without permanently removing organisms, sediments, rocks, or other samples. The video and images can be used to help researchers conduct surveys on the number of marine animals or other marine features. Videos can also be returned to study in detail later if field-time is limited.

2. Watch Kendall Roberg's "Underwater Color Loss With GoPro 0 to 155 Feet Depth - Fishing Lure Deep Test" at https://www.youtube.com/watch?v=AAJjdA6b4Ts. As the depth increases, the colored tubes appear to be more blue, green, or red? (circle one).

Blue Green Red

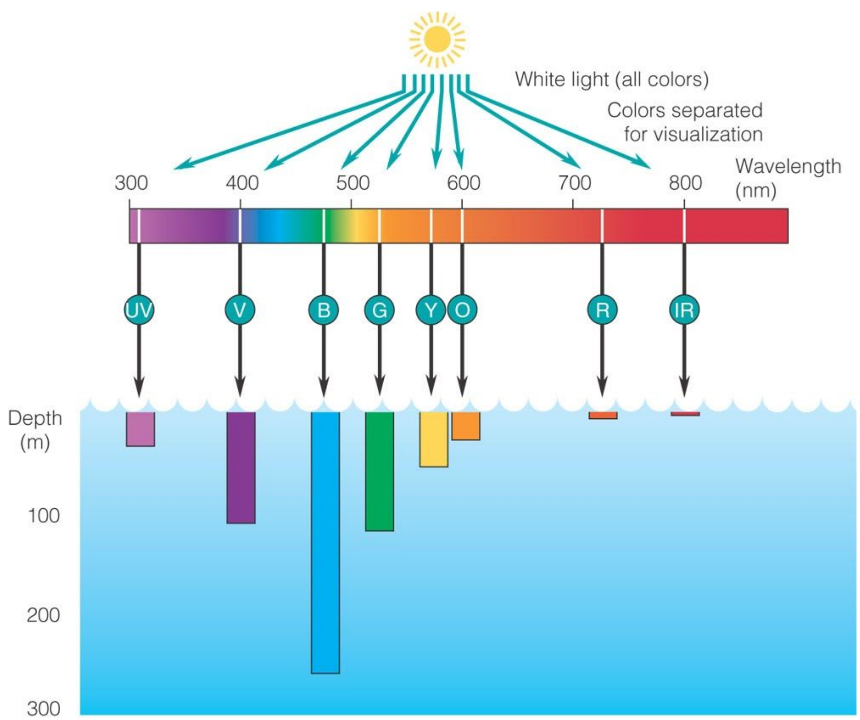
3. Why does ROV *Hercules* need so many powerful lights?

There is no light at most of the depths ROV *Hercules* explores. Even in shallower depths where there light the red light is absorbed and scattered making everything appear bluer. Bringing its own lights solves both of these problems for the researchers using ROVs.

4. ROV *Hercules* is equipped with a set of green laser beams set parallel and 10 centimeters apart. This tool is important because water refraction makes objects underwater appear larger (up to 33% larger!) than they would in the air. The lasers allow ocean explorers to measure the size of organisms and ocean features.

Within the underwater science field, use of both red lasers and green lasers are common. Based on the graphic at right, why might engineers have chosen green lasers for ROV *Hercules*?

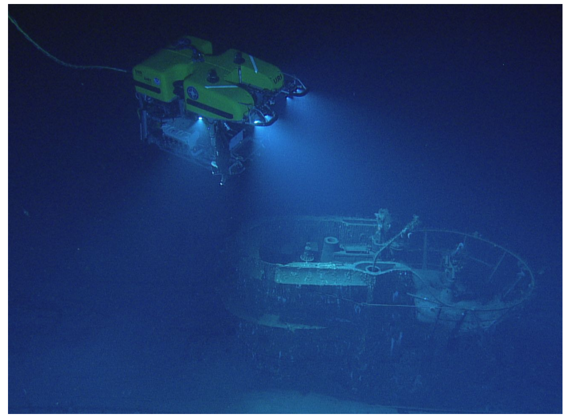
Red light does not penetrate, or travel, as far as green light can travel. When looking at objects far-away the green lasers are easier to see and more clear in recordings.



Student Worksheet

Name: ______________________________

Introduction |



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Without lights, it would be impossible for ROV cameras to see the seafloor habitats and creatures. Because light travels differently through water than through air, and colors of light behave differently, bringing light underwater introduces challenges. Dive depth and lighting configuration mpact the apparent colors cameras record. Calibrating video cameras is essential to capture the best scientific data.

In these series of activities, you will explore how refraction, the bending of light, can change how we see the world and how the energy-level of different colors of visible light determines the depth a color of light can travel.

1. Why do you think ROVs are important when studying deep ocean environments?

2. Why is it important for these ROVs to be equipped with powerful white lights when they record video and take images below the ocean's surface?

Vocabulary

- Absorption of light occurs when water takes in energy from light waves
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- ROV (Remotely Operated Vehicle) is a tethered underwater mobile vehicle.
- Scattering occurs when light is diffused through a medium.

Materials

- ❏ 3 small glass beakers
- ❏ 3 pennies
- ❏ Black card with blue, green, orange, purple, red, and yellow construction paper patches or fish outlines glued or taped on.
- ❏ Blue filters

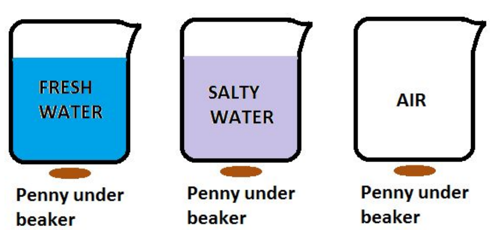
Activity 1 |

The ocean can be divided into different layers based on salinity, temperature, and levels of light. Light and other waves like sound can be refracted (bent) so that it changes what we see. Light waves can be absorbed so that we don't see those absorbed colors or light or hear the absorbed sound waves. Waves can be scattered. Scattered light waves look cloudy, rather than banded or individual points of light.

Research question: How does the medium light travels through change what we see?

Procedures:

1. Place a penny under a beaker of 80mL fresh water, a beaker of 80mL salty water, and an empty beaker.
2. Line the beakers in a straight line like the picture.
3. While standing, look down at all of the pennies under the three different beakers so that you see them all at the same time.
4. Slowly lower yourself from standing to a crouching position keeping your eyes on the pennies.
5. Observe the pennies slowly disappearing until two of the pennies have appeared to change from small slivers of pennies to completely gone.



6. Record your observations of how the medium you viewed the pennies through changed what you saw.

Activity 2: Cooking oil in a glass jar teacher demonstration |

Research question: How does the medium light travel change what we see?

1. Record what you see during this demonstration.

2. Light in the beakers from part one and in the cooking oil and glass jar from part two was

a) absorbed	(b) transmitted straight through	(c) bent	(d) scattered - looks hazy or cloudy

(a) absorbed (b) transmitted straight through (c) bent (d) scattered -looks hazy or cloudy

Part 3 |

The human eye can only detect the visible spectrum of light. The color of light we see depends on what wavelength of colored light enters our eyes. Light can be reflected or scattered to enter our eyes. Light that is absorbed by an object will not enter our eyes.

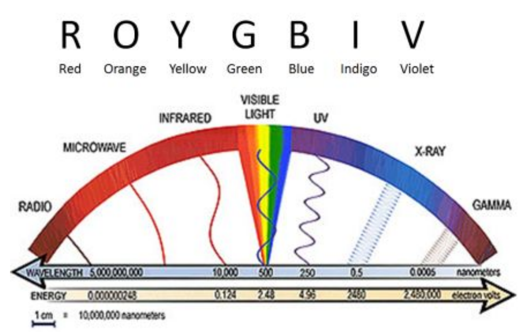


Image modified from

https://chandra.harvard.edu/resources/em_radiation.html

1. Color of GREEN laser dot:

Tape color	White	Green	Purple	Red	Burgundy	Gray	Orange	Neon orange	Neon pink
Color of the light, you see.									

2. Color of RED laser dot.

Tape color	White	Green	Purple	Red	Burgundy	Gray	Orange	Neon orange
Color of the light, you see.								

3. For part three light was_______: (Circle one)

a) absorbed	(b) transmitted straight through	(c) bent	(d) scattered - looks hazy or cloudy

Activity 4 |

1. Look at the green laser light as it shines through the CLEAR water in a fish tank. Compare this to the red laser dot. Describe what you see.

____

____

2. Add 400 mL of whole milk to the water to simulate turbid conditions in water. Look at the green laser light as it shines through the CLOUDY water in a fish tank. Compare this to the red laser dot. Describe what you see.

____

____

3. Light in the CLOUDY water tank was _______: (Circle one)

a) absorbed and bent	(b) transmitted straight through	(c) bent	(d) scattered - looks hazy or cloudy

Activity 5 |

Background information: Blue travels the farthest through ocean water of all the colors of visible light. Other colors are "lost" through absorption and scattering. Animals use this to their advantage to help camouflage themselves in deep ocean water.

1. Prediction: When placed on a black background, like would be found at ocean depths, which three colors will blend-in the most with the background when viewed through a blue filter? Circle your three choices.

   blue, green, orange, purple, red, yellow

2. Place the six different color squares, or fish cutouts, on a piece of black construction paper.
3. Look at the different color squares, or fish cutouts, on a piece of black construction paper through the blue filter. Record which three colors blend the most with black background. Circle your three choices.

   blue, green, orange, purple, red, yellow

4. If you were a fish living in the deep water, would you prefer to be green or red based on what you learned? Explain your choice.

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Blue **Green** **Red**

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