Teacher’s Notes (Answer Key: BLUE / Classroom Management & Troubleshooting: RED)

Safety Considerations

This lab uses clear nail polish, which, as you might have experience with, has an odor that might be overwhelming and may cause headaches or eye irritation (www.osha.gov). You need a well-ventilated area (e.g. fume hood, spray booth or science lab ventilation), or, a table on which to do this outside. Keep nail polish bottles capped when not actively putting a drop into your water. Hang iridescent paper to dry in a well-ventilated space outside (string and clothespins work well to create a line for drying outside). Once dry, the paper is odorless.

We used the Pure Ice brand of clear nail polish (found at Walmart, $7.00 per 0.5 fluid ounce bottle). It is formaldehyde free, dibutyl phthalate (DBP)-free, and toluene-free. Look for brands that are marked free of these ingredients which have more serious side effects. We do not recommend using any nail polish with DBP, formaldehyde, or toluene.

Personal Protective Equipment such as including indirectly vented chemical splash goggles meeting the ANSI/ISEA Z87.1 D3 standard, non-latex plastic aprons and non-latex vinyl gloves are required during the setup, hands-on, and take down segments of the activity. To protect clothing, gloves and aprons should be made available. Avoid contact with the eyes and skin. Keep away from food and drink. Wash hands with soap and water once the activity is complete.

Supplies:

- To demonstrate CMY (cyan-magenta-yellow) color mixing you will need: either 3 transparent rulers in cyan, magenta, and yellow colors, or three transparencies in CMY colors, found at https://www.exploratorium.edu/snacks/three-little-pigments. (Rulers work better).
- You will need a small amount of Red – Green paint, and Q-tips for brushes, paper plates to mix paint on. Each student group needs enough to see results from mixing EQUAL amounts.
- You can also have students go on the internet to use the interactive color mixing widgets at https://www.physicsclassroom.com/class/light
- Check out the instructible at https://www.instructables.com/id/Iridescent-Art/ for a video that shows the creation of the origami iridescent dragon head.
- To make homemade bubble solution, follow the recipe below. Straws make great bubble wands.

  Bubble Solution Ingredients
  - ½ cup dish liquid
  - 5 cups water
  - 1 teaspoon glycerin, sugar or corn syrup (add more for larger, longer lasting bubbles). Glycerin can be purchased in most drugstores and art supply stores.
  - Mix all ingredients together in a lidded container large enough to hold them.
  - Let the mixture sit overnight uncovered. Bubble solution improves with aging.

- You will also need, for each group, clear nail polish (see above, safety), a plastic shoebox, water, aquarium nets (small), colored pencils or crayons, colored construction paper, glue or hot glue, black 100 grit sandpaper, flashlights, pictures of colorful animals and plants (I suggest a cardinal, goldfinch, bluebird, and a green leaf), paper towels, and a place to hang drying iridescent paper (or a place to lay it out on paper towels – a well-ventilated place).

General Classroom Management:

- Have students work in groups of 3-4
- Watch / Warn students about safety with nail polish.
- They really only need 1-2 drops of nail polish to make a film – too much and you get "snot" building up on the surface of the water.

AGENDA: A four-day lesson on iridescence which can be done in art class, in science class, or as a collaboration between art and science teachers.

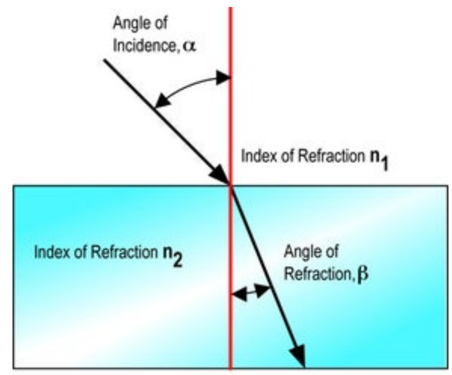
Lesson	Objective (& Time)	Activity (75 – 90 minute block)	Materials ($70 - $120 for 6 classes) – after 1st year consumables = $60
Day 1: Light Waves, Colors of Light, and Iridescence	1. Explore wave interference and relate to the iridescence seen in bubbles. (30 minutes) 2. Investigate the primary colors of light versus the primary colors of paint (pigment), and discover complimentary colors. (30 minutes) 3. Compare primary colors of light / paint. (15 – 30 minutes)	Blow bubbles: observe / describe iridescence. Graph constructive and destructive waves. Use CMY rulers to determine complimentary colors. Create Color Wheel "Rules" sheet for color subtraction (pigments/paints). Calculate color subtraction equations for bluebirds, cardinals, etc. Investigate color addition (light) with flashlights and RGB film. Specifically, use Red + Green = Yellow. Try to "add" red and green paint to get yellow. Articulate how the "Rules" sheet can show both color subtraction (for pigments/paints) and color addition (for light).	1. Bubble solution and wands – 1 per group (12 pack, $25, or make your own). 2. A flashlight ($10 for 4 pack). 3. Handout: wave interference. 4. Transparent cyan, yellow, magenta rulers; white paper/ paper plates. (https://www.exploratorium.edu/snacks/three-little-pigments) 5. Colored cellophane film (Red, Green, Blue) for flashlights (use 3-4 layers of one color per light). 6. Photos of colorful birds, flowers. 7. Red and Green paint, Q-tip "brushes", paper plate palettes.
Day 2: Making Thin Film Iridescence	Use the scientific process to make hypotheses and predictions for patterns of iridescence formed on different colored	Make thin films on black sandpaper and observe iridescence. Make thin films on Red, Blue, and Green paper, and compare the iridescent patterns on each.	1. A variety of colored construction paper or card stock (Red, Green, Blue, Yellow - $10), and black sandpaper (100 grit, $10 for 36 sheets). 2. A plastic dishpan or plastic shoebox – 1 per group (4 pack,

	paper – then test your predictions. (50 – 60 minutes)	Create a "rule" (or hypothesis) for the pattern you see. Use your rule to make a prediction for the pattern of iridescence on yellow paper. Make a thin film on yellow paper and compare to your prediction. Decide upon and iridescent animal that you would like to make as an art project, and create LOTS of thin film iridescence papers in the desired colors – Hang to Dry.	$18), and a small aquarium fish net (4 pack, $6.99 – cheap is fine, any size will do). 3. Clear nail polish (shake well) – 1 per group ($2-10 per 0.5 fl. oz. bottle). **Note**: review Safety Consideration section. 4. Paperclips and string to hang wet paper.
Day 3: STEAM Art Project	1. Create a variety of iridescent artwork based upon a real animal using the thin films made in Day 2. (30 – 60 minutes) 2. Wrap-up (15 minutes)	Use the now-dry iridescent paper "scales" created on Day 3 to create art. Projects can be as simple as gluing iridescent scales onto pre-formed animal templates, or students could make a 3-D base ("snake-head") on which to attach scales, or make an origami dragon-head and cover with scales. Students without an art background may prefer to write a story about an art project from another group. Model how bubble refraction or nail polish thin film separates wavelengths.	1. Cardstock or matting paper (150 foot roll x 18 inches, $18) to use a base for a 3-D project (instructions for folding origami dragon head and video https://www.instructables.com/id/Iridescent-Art/ that shows the creation of the dragon head). 2. Hot glue gun & glue ($10 replacement glue sticks), tape. 3. Paper templates of iridescent animals (glue or tape iridescent scales onto them), scissors, and colored construction paper and glitter foam sheets (10 pack, $10) for accents (like eyes). 4. Your iridescent "scales" made on Day 2.

Teacher Key: Classroom Strategies (In RED). Answer Key (In Blue).

Physical Science Refresher:

The diagram to the right shows the refraction of light as it passes from one medium to another. The red line is normal (perpendicular) to the surface of the material. As the light passes through the second material, the light bends towards the normal because density of the second material is greater than the first. The angle between the incoming ray and the normal is the angle of incidence. The angle between the refracted ray and the normal is the angle of refraction.



$n_1 \text{ sine } \alpha = n_2 \text{ sine } \beta$

Refraction: Refraction is the bending of light or change in direction of light as it passes from one transparent medium into another. This change of direction is caused by a change in speed.

For example, when light travels from air into water, it slows down, causing it to continue to travel at a different angle or direction. If light enters any substance with a *higher* refractive index (such as from air into glass) it slows down. The light bends *towards* the normal line. If light travels enters into a substance with a *lower* refractive index (such as from water into air) it speeds up. The light bends *away* from the normal line. A higher refractive index shows that light will slow down and change direction more as it enters the substance.

Light waves can be refracted, so can water waves. This bending by refraction makes it possible for us to have lenses, magnifying glasses, prisms and rainbows. Even our eyes depend upon this bending of light. Without refraction, we wouldn't be able to focus light onto our retina. Isaac Newton performed a famous experiment using a triangular block of glass called a prism. He used sunlight shining in through his window to create a spectrum of colors on the opposite side of his room. This experiment showed that white light is actually made of all the colors of the rainbow. These seven colors are remembered by the acronym ROY G BIV – red, orange, yellow, green, blue, indigo and violet.

Newton showed that each of these colors cannot be turned into other colors. He also showed that they can be recombined to make white light again.

The explanation for the colors separating out is that the light is made of waves. Red light has a longer wavelength than violet light. The refractive index for red light in glass is slightly different than for violet light. Violet light slows down even more than red light, so it is refracted at a slightly greater angle. The refractive index of red light in glass is 1.513. The refractive index of violet light is 1.532. This slight difference is enough for the shorter wavelengths of light to be refracted more. Source: https://www.sciencelearn.org.nz/resources/49-refraction-of-light

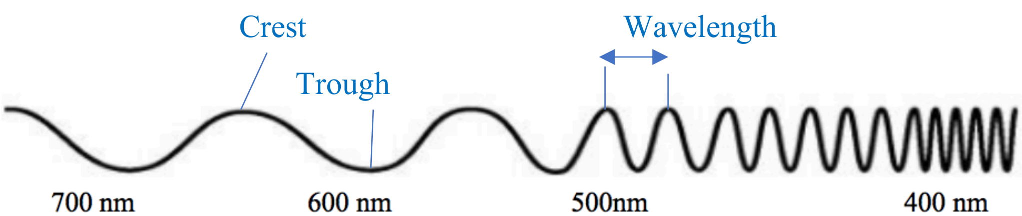
Amplitude: **the amplitude is the height of a wave, or half the vertical distance from crest to trough (or from the top to the equilibrium line, the line that is formed when there is no**

wave). The line through the center of the wave is the resting position (if there was no wave), so amplitude is the displacement from this line.

You can point out that the amplitude of a light wave is a measure of how much energy it carries – high energy waves have a high amplitude. Bigger Amplitude = Greater Brightness / Intensity (and more energy).

Wavelength: **the wavelength the distance from one point on a wave to the same point on the next wave (for example, crest to crest). With light, it is measured in nanometers (nm). The shorter the wavelength the more waves in the same frame or distance (shorter wavelength = higher frequency). Again, each wavelength = a specific color.**

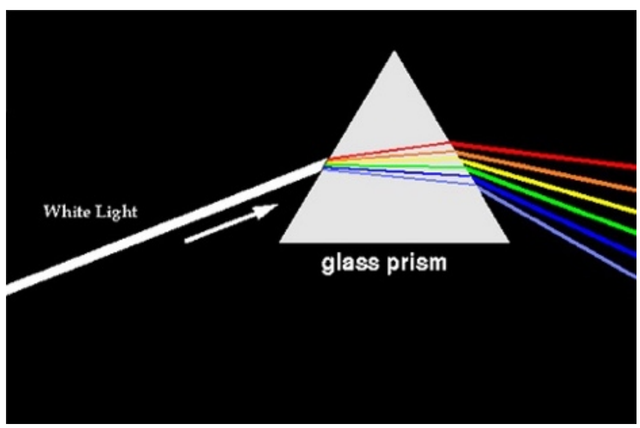
color	wavelength
red	~ 700–630 nm
orange	~ 630–590 nm
yellow	~ 590–560 nm
green	~ 560–490 nm
blue	~ 490–450 nm
violet	~ 450–400 nm



Color = ___________ __________ ___________ __________ _________ ___________

Red 700-630 | Orange 630-590 | Yellow 590-560 | Green 560-490 | Blue 490-450 | Violet 450-400

indigo isn't technically a color because the human eye can't differentiate it from blue/violet



Light exits a prism through face at a different angle to the entry face so the refraction persists past the prism. Light does disperse into its spectrum of colors in a glass slab too. For white light to pass through a glass slab or a glass prism, it is refracted not once, but twice. It first travels from air to glass and then from glass to air. At the first instance of refraction, it slows down and at the second it speeds up. So what happens in a glass slab? All the light rays slow down and speed up at the same rate because both the surfaces are **parallel**. And hence, to an observer, it would seem as if white light has entered and left the slab. But the case is different in a prism. The surfaces of a prism aren't parallel to each other and so the light rays emerging out of the prism finally follow the path that is different from each other, giving a dispersed effect.

Day 1 – Activity 1 Exploring the Primary Colors of Light and of Pigment / Paint

CLASSROOM STRATEGIES: Engage students by showing pictures of colorful animals and plants, and start a discussion, asking 'What causes color'? Answer: Pigments give things color by absorbing colors of light. Colors NOT absorbed are what we see. Keep it brief, explain the primary colors of Pigment / Paint are Cyan Magenta Yellow (probably learned as Blue Red Yellow, and often still referred to as this by artists, but science now labels pigments as CMY, because CMY are the complements of RGB – in other words if we shine white light (RGB) on something red, cyan is subtracted (not blue). A technicality, but really, CMY are the basis for all other colors in printing /digital fields (you buy computer ink in CMY and black)).

The goal is to COMPARE the primary colors of Pigment with the primary colors of Light.

Pigments: chemicals that absorb light wavelengths (colors of light). Colors that are reflected / NOT absorbed are what you see. Colors are Subtractive.

- Light: electromagnetic (sun) energy that travels as a wave, with specific wavelengths corresponding to (or interpreted by brain as) specific colors.
- White light = Red + Green + Blue (in equal amounts).
- Your eye has receptors (cones) that detect RGB only. RGB mixed in unequal amounts are interpreted as secondary colors. Colors are Additive.
- The primary colors of pigment (CMY) = secondary colors of Light (CMY) and
- The primary colors of light (RGB) = secondary colors of pigments (CMY)

Given the primary colors of pigment, CMY, can students determine complimentary colors (which get subtracted)? YES – with the ruler activity. Use this info to complete the Color Wheel Rules graphic. THEN you can do color subtraction, useful for mixing paint in desired color (art class).

Day 1 – Activity 1: Exploring the Primary Colors of Light and of Pigment / Paint

Let's explore color: Light can be divided into colors, and pigments have color too. Pigments are chemicals that absorb **light**. Each pigment absorbs a specific wavelength (color) of light, and reflects the others (this is what you see). Pigments can be biological (giving plants and animals color) or non-living (like those that give paint their color). The Primary Colors of Pigments / Paint are Cyan, Magenta, and Yellow (CMY). The Primary Colors of Light are different - Red, Green, and Blue (RGB).

What happens when colors mix? For Light: colors get added together. For pigments: the pigment in paint absorbs, or subtracts, certain wavelengths (colors) of light. For example, a yellow pigment is yellow because it subtracts blue light, and reflects yellow. **There are rules for this:** a colored pigment will absorb (subtract) its complimentary color from white light.

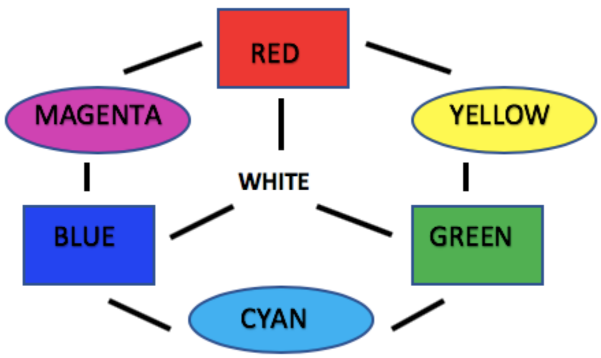
What are the complimentary colors? Use your pigment-colored rulers to figure out the color subtraction rules. You have a cyan, a yellow, and a magenta ruler. Each ruler absorbs, or subtracts, a single primary color of Light (RGB), so if you put two rulers together, two of the primary colors of light are subtracted. The color that is left over is the color you see.

Do this in Groups of 3-4 students

- Over a white plate, put two of the rulers together to form an "X". Two of the primary light colors (RGB) get absorbed, and one is left over (reflected, and visible). **Put this leftover color in the rectangular box between the two colors that formed it.**

- Try all combinations, 2 at a time, and use the process of elimination to determine the complimentary color for CMY. (Hint: It is not the "leftover" color).

- Fill out your Color Wheel "Rules". Locate your complimentary colors. **Opposite**



Color Wheel Addition & Subtraction Rules

Question: can you describe the position of the complementary colors?
OPPOSITE

Question: What are the complementary colors?
Cyan / __RED________
Magenta / __GREEN___
Yellow / __BLUE____

Note the 3 primary colors of light (RGB) – these colors of light are additive: take any two and mix (add) together, and the resulting secondary color of light (CMY) is the color in between the 2 primary colors of light on the color wheel rules sheet.

Also note the three primary colors of paint (CMY). Paints have pigments, and pigments absorb (or subtract) color. The color that gets absorbed is the complimentary color – and complimentary colors are opposite each other on the rules sheet you just created. But it is still true that if you put 2 of the CMY colors together, they make the color that is in between them on the wheel. They just make that color through subtraction, not addition.

Ruler color 1	Ruler color 2	Resulting color
Cyan	Magenta	Blue
Cyan	Yellow	Green
Yellow	Magenta	Red

Use the process of elimination to determine complimentary colors. FOR EXAMPLE: if cyan + magenta = blue, then red and green are being subtracted or absorbed. Cyan subtracts either Red or Green, and Magenta subtracts either Red or Green. BUT, using next combo, if Cyan + Yellow = Green, then Cyan must absorb either Red or Blue. So – using both combos, you can determine that Cyan absorbs Red. Cyan and Red are Complimentary and are Opposite on the wheel.

Comparing Colors of Pigment and Colors of Light: The ‘Rules’ color wheel shows the primary colors of Light (RGB) and the primary colors of Paint (CMY) – and shows the rules for subtraction and addition.

Note that if you look at RGB, the color <u>in between</u> any two primary colors of light (RGB) is the color you get when you <u>ADD</u> those two primary colors together (in equal amounts). IT IS ALSO TRUE that if you look at CMY, the color in between any two is the color that you see when those two colors are mixed together – but <u>this is not due</u> to addition. This is <u>Subtraction</u>. Each of the CMY colors <u>Subtracts</u> the complement, and one color of RGB is left over, and that is what you see. It can be confusing, since the resulting color is in between the 2 colors that form it in either case – but how the color is formed is different (additive vs. subtractive). The color subtraction practice should help solidify this.

Color Subtraction: A <u>Pigment</u> absorbs, or <u>Subtracts</u>, its complementary color from RGB Light. The color you see is the color that isn’t absorbed. Equal amounts of CMY subtracts all the RGB, and results in what we call ‘black’ (absence of light colors). This is what makes CMY the “primary” colors – equal amounts make black via subtraction.

Color Addition: The colors of <u>Light</u> are <u>Additive</u>. White light is Red, Green, and Blue (RGB) mixed (added) together equally – but if you have just two of the primary colors of light, they add together to make the color you see (if added in equal amounts, two together will make a secondary color of light: Cyan, Magenta, Yellow). On your Color Wheel Rules, the color formed by adding two of the 3 primary light colors (RGB) is found <u>in between</u> those two colors.

<u>Practice with Color Subtraction (Pigments):</u> Fill out the following table, which illustrates <u>color subtraction</u> for the primary colors of pigments. For each photograph of a plant or animal write out the color subtraction. For example, why is a bluebird blue? White light shines on feather pigments that reflects Blue, but absorb Yellow (its complement). Yellow is Red + Green. If Red and Green are absorbed, all we will see is the Blue that gets reflected.

Animal’s color	**Color(s) Reflected**	**Color(s) absorbed (= complimentary color)**	**Color Subtraction White – Color Absorbed = Color Reflected**
Bluebird = Blue	Blue	Yellow (Red + Green)	RGB – Yellow = RGB – (R+G) = Blue
Cardinal = Red	Red	Cyan (Green + Blue)	RGB – Cyan = RGB – (G+B) = Red
Goldfinch = Yellow	Yellow (R+G)	Blue	RGB – Blue = Green + Red = Yellow
Leaves = Green	Green	Magenta (Red + Blue)	RGB – Magenta = RGB – (R+B) = G

Table 1. Students explore the primary colors of paint and the primary colors of light using a science snack from Exploratorium. They determine the rules of color subtraction for pigments / paints, then the rules for color addition for the primary colors of light after creating a graphic to use as their ‘Rules Cheat Sheet’. **Answer Key.**

We can write this as White Light – Color Absorbed = Color Reflected

This is the same thing: RGB (white light) – (R + G) (yellow, expressed as primary light colors) = Blue (reflected)

You need to know color subtraction in order to figure out which primary paint colors to mix together to make the secondary paint colors (RGB).

Question: What primary **paint** colors do I need to mix together to create Red**?** **Magenta + Yellow**

Question: What primary **paint** colors do I need to mix together to create Orange?

Magenta + Yellow (but more Yellow than Magenta)

(like in kindergarten, mixing Red + Yellow = Orange)

Practice with Color Addition (Light): Color addition happens when the colors of light (not pigment) are mixed: White light is Red, Green, and Blue (RGB) mixed (added) together equally. Unlike colored pigments, the colors of light are additive – you add 2 primary colors of light together to make a Secondary Color of Light (Cyan, Magenta, Yellow). **Check** your rules sheet by adding light colors, two at a time, using flashlights and colored film. **Take three flashlights, each with one color of cellophane film rubber-banded over light. Use 4 layers of each film. Darken room, aim flashlights at a white wall or paper plate. Put 2 colors together = "Add" a color by shining another flashlight beam, with green film, on top.**

Bottom line: The colors of light and the colors of pigment do NOT mix in the same way.

Can you think of any instance where you can take two colors of paint, and mix them to create a third color - and then take the same two colors of light and mix them to create the same third color? **Nope.**

Try it: put equal amounts of Red and Green Paint together (you just need a tiny amount). According to the addition rules for the Colors of Light, if you add red and green light -

Put equal amounts of Red and Green Paint together (you just need a tiny amount). According to the addition rules for the Colors of Light,
What color SHOULD you get? (Red Light + Green Light = _**Yellow**_______)

What color DO you get? (Red Paint + Green Paint = ____**Brown**__________)
Why do you think this is? **Because pigments / paints work under the color subtraction rules, but light works under the color addition rules.**

**** this could be a prime spot for misconceptions – so you should, if you can. Have student do this exercise - the colors of paint and the colors of light DO NOT mix in the same way.**

<u>Day 1 – Activity 2</u> **<u>Engage with Bubbles and Explore Wave Interference</u>** (Can also be done on Day 2 if you run out of time, or have a shorter block)

1. Blow some bubbles outside, or over a carpeted area (soap bubbles on tile flooring will make it slippery). If you can, hold a bubble on a bubble wand or straw in front of a piece of black paper. **Describe what you see: many bright shimmery colors swirling, in motion … The bubbles are transparent, but have <u>swirling</u> colors of the rainbow on the surface. The colors seem to fade or disappear right before it pops.**

2. Sketch the Bubble

A soap bubble is like a water sandwich – it is two layers of soap film with a layer of water in between. Light can reflect off either the top or bottom layer as some light passes through the top layer of soap, gets refracted by the water, and then reflects from the bottom layer. The iridescence of a soap bubble comes from light striking the thin bubble film from many angles. The light absorbed by the thin film of soap is **reflected** and **refracted**, and splits into various colors depending upon the thickness of the film, the angle that light enters, and the amount of **interference** (some light reflects from the top layer of the soap film, some light reflects from the bottom layer). When the waves meet, they interfere. As the light waves travel through the bubble they collide with each other. If they collide crest to crest, then they reinforce each other's impact and effects, causing **constructive interference**, and bright colors in that wavelength. But if the waves meet crest to trough, they cancel out each other's effect, and the result is **destructive interference**, and dimmer or missing colors in that wavelength. Eventually, the soap film evaporates and becomes too thin to create interference of visible wavelength; at this point the bubble appears colorless – then pops!

The soap bubble:

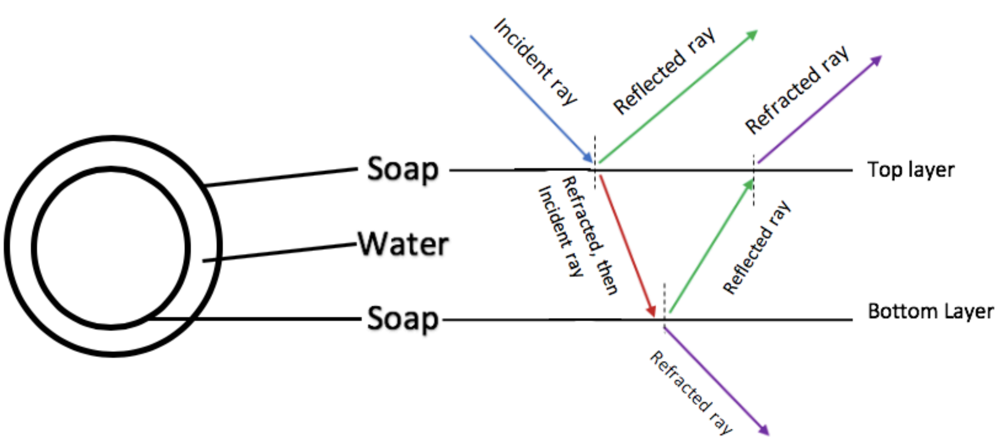


Figure 3. A soap bubble is a thin film, with two soap layers and a water layer in between. Water has a higher refractive index than air, and so light, passing through the top or outermost soap layer, will refract when it travels through the water layer.

Iridescence:
When white light strikes a thin, transparent film, some of the light reflects off the top surface of the film and some of the light reflects off the bottom surface (Figure 1). Light striking the thin film is separated, combined, then reflected, but the wavelengths coming from the top versus bottom may **interfere**, and may be in phase, or slightly off. As the waves travel through the film they interfere, or collide with each other, and a rainbow effect called iridescence is created (Figure 2). If the waves collide crest to crest, then they reinforce each other's impact, causing constructive interference and a brighter intensity. If the waves meet crest to trough, they cancel out each other's effect, and the result is destructive interference, and dimmer colors.

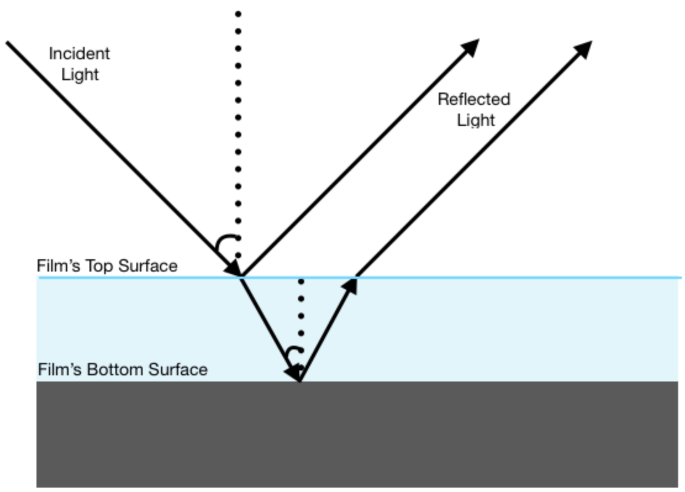


Figure 1. When white light strikes a thin, transparent film, some of the light reflects off the top surface of the film and some of the light reflects off the bottom surface. Eventually, the light that is reflected off the bottom surface will meet with the light that reflected off the top of the film. Some wavelengths are intensified and appear brighter (constructive interference), others are muted (destructive interference), and a rainbow effect called iridescence is created.

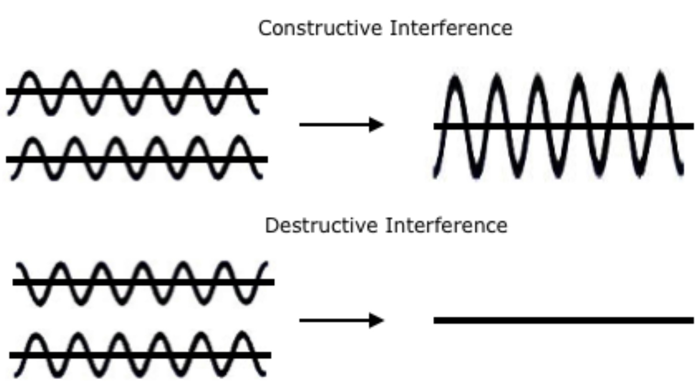
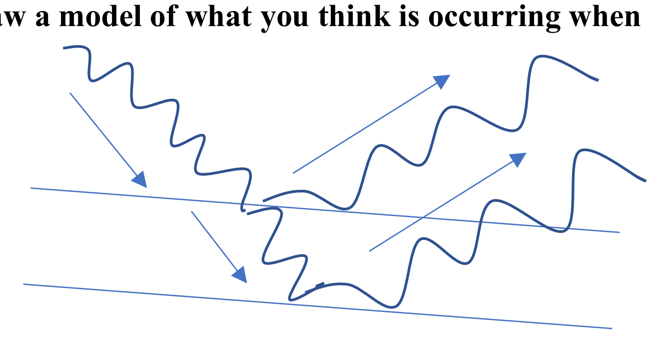


Figure 2. The resultant wave formed when two waves meet can be either larger, with a greater amplitude, when constructive interference occurs, or smaller, with a smaller amplitude when destructive interference occurs. Since amplitude is a measure of light intensity (or brightness), when waves get larger due to constructive interference, they appear brighter. Iridescence has both brighter and muted waves, and appears "shimmery".

3. Do the Wave Graphing Exercise now – it is on a separate worksheet (Handout #2), use as formative assessment. Connect amplitude with brightness/intensity. If light waves meet constructively, amplitude increases, the resulting color is more intense / bright: iridescence!

4. Draw a model of what you think is occurring when light strikes a bubble.



DAY 2 – Making Thin Film Iridescence

Activity 1: We are going to make iridescent paper, using a thin clear film to separate light. Do this first on a piece of black sandpaper.

Activity 2: Now, let's do some experimenting. We will use science practices to figure out what colors of iridescence we will find if we use different colors of paper as a base. Can you see a pattern?

Following the procedure, **make** thin film iridescence using red, blue, and green paper.

Then, **analyze** the patterns you see in your iridescent paper (fill in data table 3) and make a hypothesis.

Last, **predict**: what do you think the iridescence would look like on yellow paper?

CLASSROOM MANAGEMENT: **Work in Groups of 3-4 students, each group with a plastic bin with approx3-4 inches water. Each group needs 1 bottle clear nail polish, 1 fish net, and a variety of RGBY paper, and black sandpaper. PRE-CUT the paper into approx. 3 inch by 3 inch squares.**

With nail polish, shake 1-2 drops in the water, it will spread out – wait a few seconds for it to spread and "harden" then capture with paper.

Watch for students pulling paper out too quickly – you want to capture the film as a sheet, plunging paper in and out too quickly causes clumping of the film. Also, aim for one layer, don't dip in and out repeatedly. Use nets to skim excess film off surface after 4-5 papers are made. Have paper towels handy.

Have a plan for orderly progression - a student drops the polish, takes the paper and dips it, then walks it to the line to hang, and the next student in the group makes their film, same orderly progression, keep rotating through the cycle until everyone has made a film. I have each group make 1 film on sandpaper then 1 on R, G, B paper (4 total). Then, we look for patterns. Then, we decide what / how many films we want for our project and spend the rest of the class rotating / making films / hanging films. At 5 minutes prior to end of class have groups dump water, re-fill, and use sponges/paper towels to clean up.

I have VERTICAL yarn hanging from a longer horizontal clothesline – each vertical line is for one student, or one group, and a name is at the top. This way they don't get papers mixed up the next day. Paperclips work fine to attach paper to line. With adequate corkboard you can tack papers up. In a pinch you can spread on a table as well, film side up, I haven't had them stick.

Procedure: making iridescent paper

1. Take a plastic dishpan and fill it with about three inches of water.
2. Over the center of the pan let one drop of clear nail polish fall onto the water.
3. Wait about 30 seconds.
4. Put a 3x3 inch piece of paper into the pan, SLOWLY sliding it at an angle DEEP under the nail polish film, then lift it by one corner to catch the film on the paper.
5. After you have done steps 2-4 several times you will need a small aquarium net to remove excess film from your water, then keep on going.
6. Let paper dry overnight (hang it, or place it on a paper plate or paper towel).
7. Once dry, the paper can be used in your art project by simply cutting out the shapes and sizes you need.
8. After making thin film iridescent paper using red, blue, and green paper, fill out your data table and analyze the patterns you see.
9. Next make a hypothesis to explain your pattern.
10. Last, **predict** – If your pattern, or hypothesis, is true, what do you think the iridescence would look like if you used **yellow** paper?

Hypothesis: **each specific paper color will absorb its complimentary color when white light (RGB) shines on the paper. Complimentary colors therefore will mostly be absent. (IF the paper color absorbs the complimentary color, THEN the complimentary color will be absent in the iridescence)**

Prediction: what do you think the iridescence would look like if you used **yellow** paper?
Because Blue is the complement of Yellow, iridescence on yellow paper should have a lot of yellows and greens and reds, but few blues.

Paper Color (is reflected)	Complimentary Color (is absorbed)	Colors you saw a LOT of in iridescence	Colors you saw only a little / none of in iridescence
Red	Cyan (= Blue and Green)	Red Yellow Magenta	Cyan (Blue / Green)
Blue	Yellow (= Red and Green)	Blue Green Magenta	Yellow (Red / Green)
Green	Magenta (= Red and Blue)	Green Yellow Cyan	Magenta (Red / Blue)
Yellow	Blue	Yellow Green Magenta	Blue (Cyan / Magenta)

Table 3. Students hypothesized that each specific paper color will absorb its complimentary color when white light (RGB) shines on the paper. Students then test the prediction for yellow paper by making thin films with nail polish.

DAY 3 - The Art Project

A video is embedded at https://www.instructables.com/id/Iridescent-Art/ that shows the creation of the dragon head. Directions for origami dragon heads, snakes, and birds are easily found on the web. Use 18-inch x 18-inch black matting paper to fold larger pieces. Students will make iridescent paper and cut out shapes – scales for dragons, for example. Use hot glue to attach scales to the origami frame, or to drawings of iridescent animals.

Here is a good spot for differentiation - some students may be advanced in art, and want to do the origami frame. Others may prefer something simpler – fold a piece of paper into a cone for a bird or snake "head", or print out the iridescent animal templates and simply cut out pieces to match wings, etc, and glue on. Some students are capable of doing a big art project together, others may need to work solo, in which case the smaller project is better. Each group should have a glue gun. Some students who are not creatively inclined may prefer an ELA project, making a story about the art creation of another group.

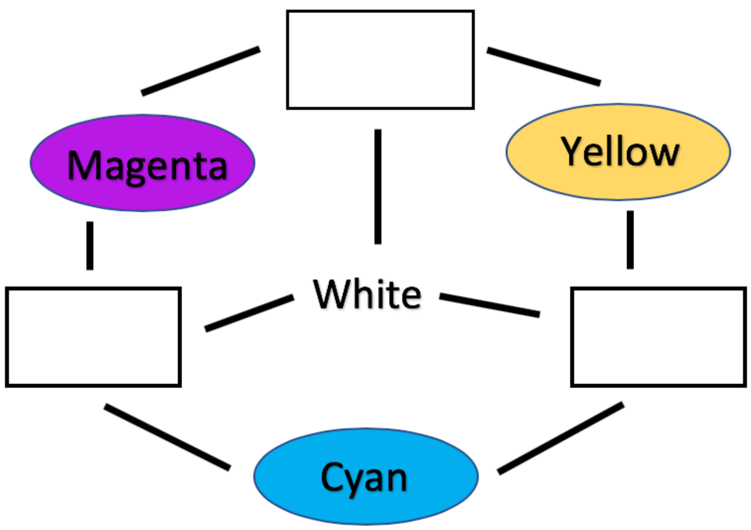
WRAP – UP: Connect amplitude with brightness/intensity. If light waves meet constructively, amplitude increases, the resulting color is more intense / brighter: iridescence! Iridescence is caused by wavelengths meeting both constructively and destructively, so some colors are brighter, some are muted.

When white light strikes a thin, transparent film, some of the light reflects off the top surface of the film and some of the light reflects off the bottom surface. Light striking the thin film is separated, combined, then reflected, but the wavelengths coming from the top versus bottom may interfere, and may be in phase, or slightly off. As the waves travel through the film they interfere, or collide with each other, and a rainbow effect called iridescence is created. If the waves collide crest to crest, then they reinforce each other's impact, causing constructive interference and a brighter intensity. If the waves meet crest to trough, they cancel out each other's effect, and the result is destructive interference, and dimmer colors.

Have students explain how the bubbles are thin films, like our nail polish films, and so appear iridescent. Then ask how the prism activity we did is similar. Thin films separate light – just like the prism did – but with a thin film, the separated light gets reflected and combined – and if waves combine constructively / destructively, the intensity / brightness changes.

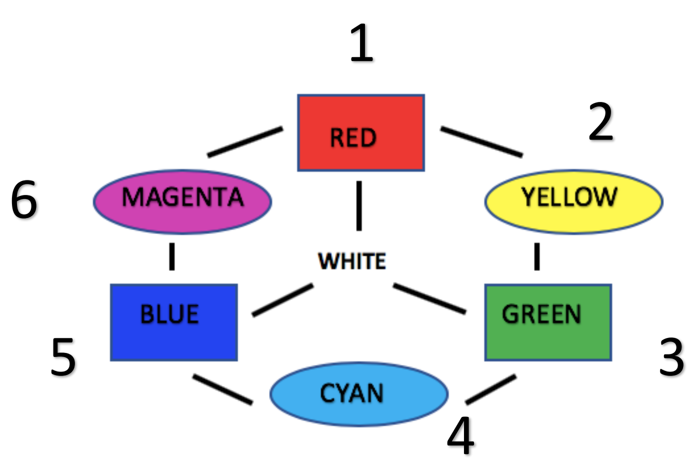
Exit Ticket: Fill in the rectangles with their correct primary light colors.

Put Numbers by each color to show wavelength (Longest is #1, Shortest is # 6 – do not include white). Can you see a pattern with color and wavelength? What is it?

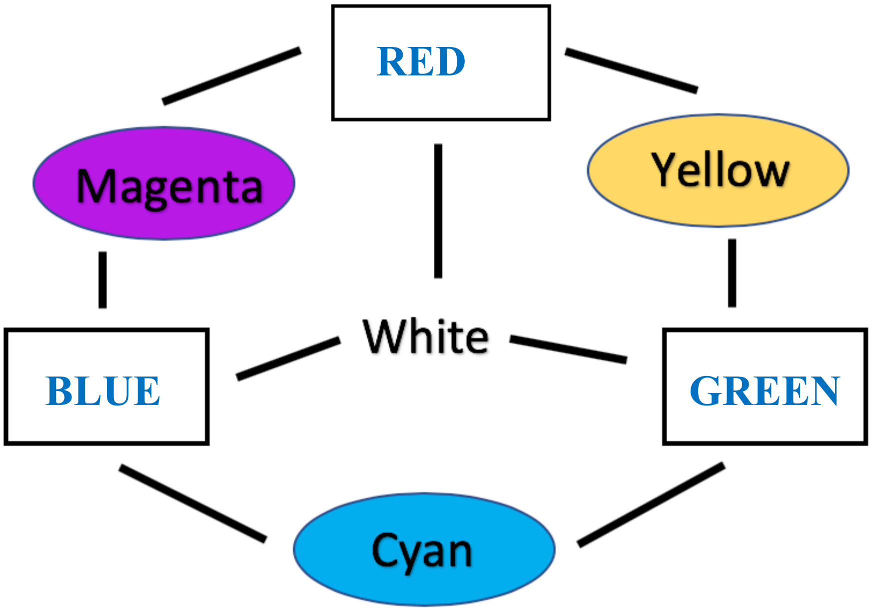


Exit Ticket Answer Keys:

This is the completed Rules Cheat Sheet – it should match ROYGBiV, though orange and violet aren't on here. Students see that cyan is between green and blue (so around 490 nm), and magenta is between blue and red (and is a special case of a color that is more than one wavelength). Red has the longest wavelength at 700 nm, and Violet has the shortest at 420 nm. On our chart, blue has a wavelength of 470 nm – and magenta is a special case with no actual wavelength attributed to it as it is actually a tertiary color (a mix of a full saturation of one color and half saturation of a second color). For our purposes we will leave it as #6, close to violet. The pattern is this: the numbers circle clockwise, with red (#1) having the longest wavelength and wavelengths get shorter as you move clockwise.



RULES
(answers)



Complementary Colors:

Cyan / _RED____ **Magenta / __GREEN_____** **Yellow / ___BLUE______**

Primary Colors of Pigment

CYAN MAGENTA YELLOW

(all 3 in equal amounts = ____BLACK______)

Mixing Primary Paint colors is done by

__SUBTRACTION__________

Example:

Magenta + Yellow = ___Red__
= RGB – G – B =
White light – Complement of Magenta – Complement of Yellow = **Red**

Cyan + Yellow = __GREEN_______

Cyan + Magenta = __BLUE_____

Primary Colors of Light

RED GREEN BLUE

(all 3 in equal amounts = _____WHITE_____)

Mixing Primary Light colors is done by

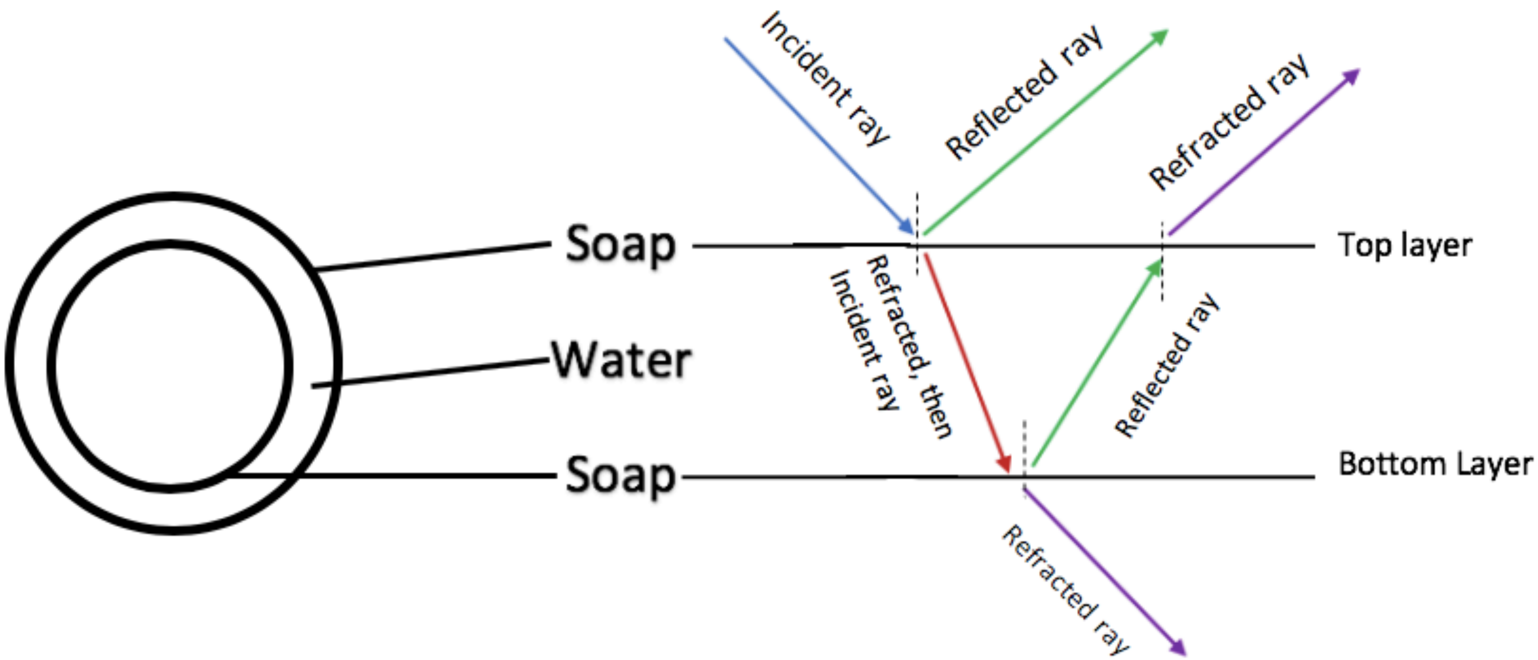
_____ADDITION_________

Example:

Red + Blue = Magenta
(look between Red and Blue on the Color Wheel)

Red + Green = _YELLOW_____

Blue + Green = CYAN_____


Soap
Water
Soap
Incident ray
Reflected ray
Refracted ray
Refracted, then Incident ray
Reflected ray
Top layer
Bottom Layer
Refracted ray