Light Waves and Matter

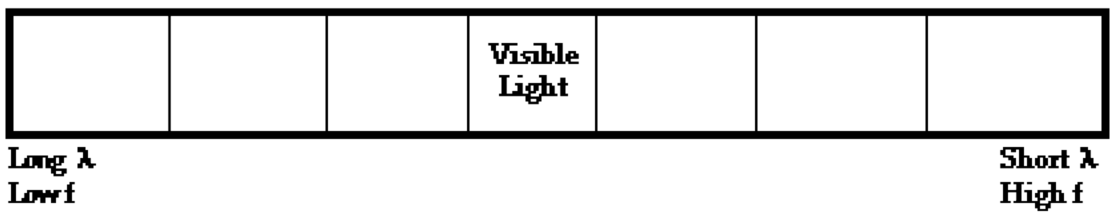
Read from **Lesson 2** of the **Light Waves and Color** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/light/u12l2a.html

MOP Connection: Light and Color: sublevel 1

1. A light wave is an electromagnetic wave which has both an electric and magnetic component associated with it. Electromagnetic waves are often distinguished from mechanical waves. The distinction is based on the fact that electromagnetic waves ______.
   a. can travel through materials and mechanical waves cannot
   b. come in a range of frequencies and mechanical waves exist with only certain frequencies
   c. can travel through a region void of matter and mechanical waves cannot
   d. electromagnetic waves cannot transport energy and mechanical waves can transport energy
   e. electromagnetic waves have an infinite speed and mechanical waves have a finite speed

2. Consider the diagram below. It represents the beginnings of an electromagnetic spectrum below. Complete the diagram by labeling the following regions: ultraviolet, infrared, x-ray, radio wave, gamma radiation, and microwave radiation.



3. Which region of the electromagnetic spectrum has the highest frequency?

4. Which region of the electromagnetic spectrum has the longest wavelength?

5. Which region of the electromagnetic spectrum will travel with the fastest speed?

6. It is known that electromagnetic waves with longer wavelengths have a greater ability to bend around obstacles which get in their path. This ability to bend around obstacles is referred to as diffraction. Electromagnetic waves with strong diffraction properties are used in communication. Which two regions of the spectrum have the greatest ability to diffract?

7. It is known that electromagnetic waves with high frequency are more capable of causing damage to the organs of living things. Which two regions of the spectrum have the tendency to cause the greatest damage to humans?

Light and Color

Light which the human eye is capable of detecting is known as visible light. There are a range of frequencies which the eye can detect. Various frequencies are observed as different colors. The diagram below represents the range or spectrum of visible light frequencies labeled with their respective colors.

Infrared	Red	Orange	Yellow	Green	Blue	Indigo	Violet	Ultraviolet

8. Which color of the visible light spectrum has the highest frequency?

9. Which color of the visible light spectrum has the longest wavelength?

10. Light and material objects always interact in one way or another. When light is incident on some materials, it is transmitted through the material. For instance, visible light is transmitted through glass. Glass is said to be _______ to visible light.
    a. transparent   b. opaque

11. Other materials absorb and/or reflect light only. They do not allow light to pass through it. Such materials are said to be ________.
    a. transparent   b. opaque

12. Some material objects are transparent to certain forms of electromagnetic waves but opaque to other forms. Earth's atmosphere is an example. The atmosphere allows visible light to pass through it. Much of the more damaging portion of the ultraviolet spectrum is blocked by a thin layer of ozone in the stratosphere. The atmosphere is said to be ____________________________ (transparent, opaque) to visible light but ______________________________ (transparent, opaque) to ultraviolet light.

13. As light passes through transparent objects, the speed at which it travels is __________.
    a. the same speed as it travels through air
    b. less than the speed at which it travels through air
    c. greater than the speed at which it travels through air

Polarization

Read from **Lesson 1** of the **Light Waves and Color** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/light/u12l1e.html

MOP Connection: Light and Color: sublevel 2

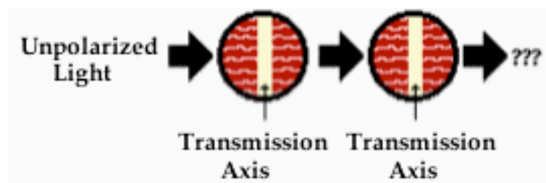
1. When a light wave vibrates in a variety of directions, the light is said to be ____.
   a. transverse b. polarized c. unpolarized

2. When a light wave's are isolated to a single plane, the light is said to be ____.
   a. transverse b. polarized c. unpolarized

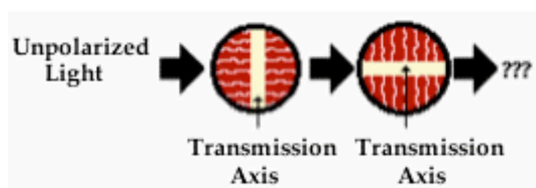
3. A Polaroid filter polarizes light by _________.
   a. re-orienting all the wave vibrations such that they vibrate in a single plane
   b. blocking part of the vibrations while letting through those which are in a specific plane

4. Filters allow light to pass through. Polaroid filters are very selective about the orientation of the light vibrations which are allowed through. The light which passes through a Polaroid filter is vibrating in a direction which is ____________.
   a. parallel to the orientation of the molecules which make up the alignment
   b. parallel to the polarization axis or transmission axis of the filter
   c. parallel to the ceiling or the sky (if the source of light is on the ceiling or in the sky)
   d. always horizontal, regardless of what the light source is

5. Describe the result of shining light through two polarizing filters whose transmission axes are parallel to each other. Describe the intensity and the orientation of the emerging light.

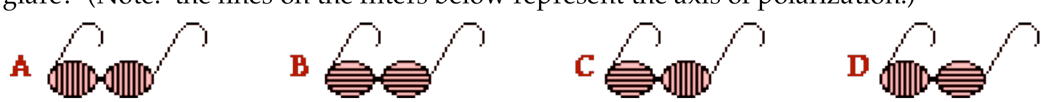


6. Describe the result of shining light through two polarizing filters whose transmission axes are perpendicular to each other. Describe the intensity and the orientation of the emerging light.

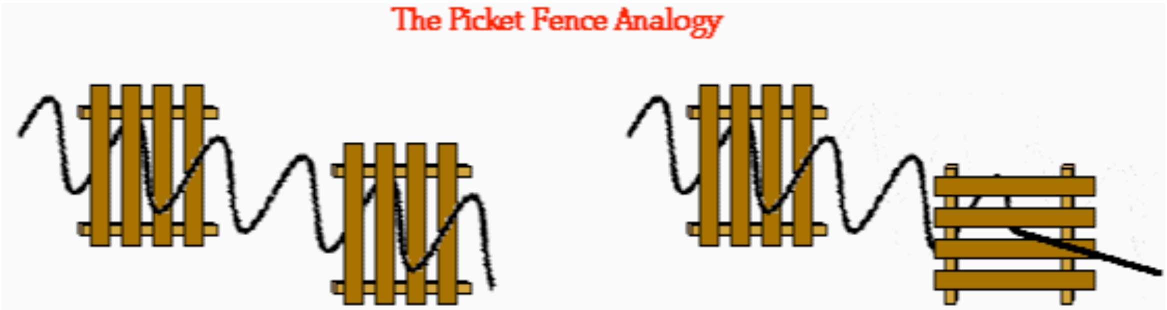


7. Passing light through a Polaroid filter is not the only way that unpolarized light can be polarized. Light is also polarized when it reflects off non-metallic surfaces. When light reflects off nonmetallic surfaces such as glass, water, or a road surface, the light is partly polarized. The reflected light consists of waves which are vibrating mostly _____ to the reflecting surface.
   a. parallel b. perpendicular

8. Carson Busses is driving down the road on a sunny day. Reflection of light off the road surface results in a large amount of polarization and a subsequent glare. Annoyed by the glare, Carson pulls out his Polaroid sunglasses. How must the axes of polarization be oriented in order to block the glare? (Note: the lines on the filters below represent the axis of polarization.)



9. The *picket fence analogy* is often used to explain observations such as that in questions #5 and #6. Use the picket fence analogy to explain your answers to questions #5 and #6. Make reference to the diagrams below in your explanations.



10. Another application of polarizing filters is in the production and viewing of three-dimensional movies. The goal of the production and viewing process is to present a scene from the movie in such a manner that it is perceived in three dimensions despite the fact that it is projected onto a flat, two-dimensional screen. Normal 3-D perception of the world is the result of viewing it with two eyes located is slightly different positions. This *stereoscopic vision* can be reproduced in film if the scene of a movie is filmed with two different cameras slightly offset from each other. Once filmed, the two movies are projected onto a flat metallic screen in the theater. Those viewing the film then watch the two movies through Polaroid glasses. To create the perception of the three dimensions, one eye must view one of the movies and the other eye must view the other movie. This is done using Polaroid filters. Each movie is projected through a Polaroid filter onto the screen. The transmission axes of the filters are perpendicular to each other. The viewers where Polaroid filters over each eye; but the transmission axes of the glasses are perpendicular to each other. Thus, one eye sees one of the projected movies and the other eye sees the other projected movie. As a result, the scene of the movie is perceived as three dimensional.

Reflection, Transmission and Color

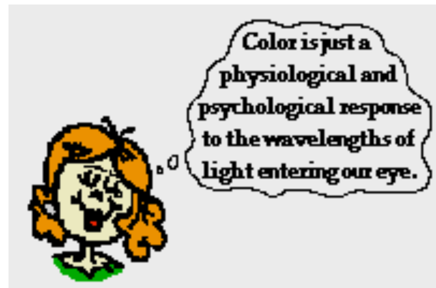
Read from **Lesson 2** of the **Light Waves and Color** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/light/u12l2a.html
http://www.physicsclassroom.com/Class/light/u12l2b.html
http://www.physicsclassroom.com/Class/light/u12l2c.html

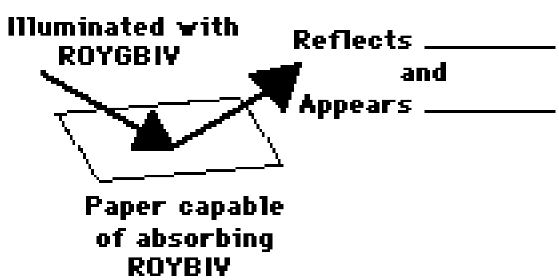
1. Visible light is composed of a range of wavelengths; different wavelengths correspond to different colors. Identify the seven component colors of visible light.

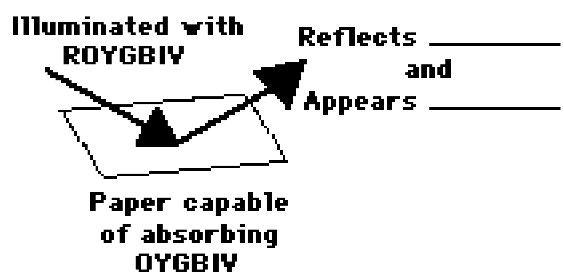
_________ _________ _________ _________ _________ _________ _________

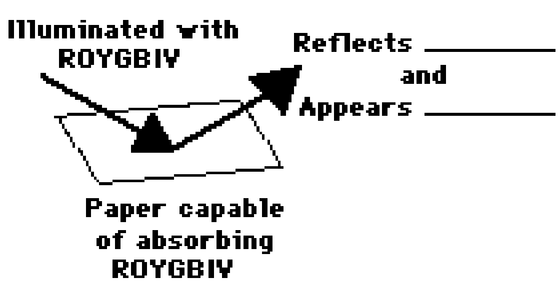
2. Natural philosophers have long pondered the underlying reasons for color in nature. One common historical belief was that colored objects in nature produce small particles (perhaps light particles) which subsequently reach our eyes. Different objects produce different colored particles, thus contributing to their different appearance. Is this belief accurate or not? __________ Justify your answer.

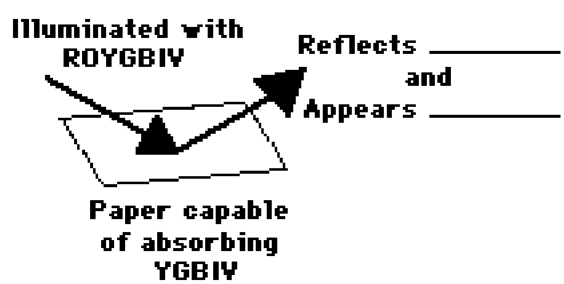


3. The color which an opaque object appears is dependent upon what color(s) of light incident upon the object and the color(s) of light reflected by the object. Express your understanding of this principle by filling in the blanks in the following diagrams.





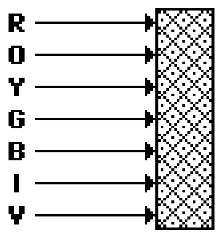




4. Two students in the cafeteria are discussing the physics of color. The students are claiming that <u>white and black are not really colors of light</u>. If white and black are not really colors of light, then what are they? Explain fully.

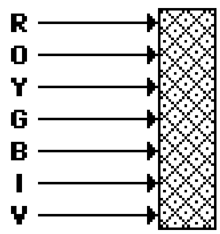
5. Explain why a red shirt looks red when visible light ("ROYGBIV") shines upon it.

6. Transparent materials are materials which allow one or more of the colors of visible light to be transmitted through them; whatever color(s) is/are not transmitted by such objects, are typically absorbed by them. The appearance of a transparent object is dependent upon what color(s) of light is/are incident upon the object and what color(s) of light is/are transmitted through the object. Express your understanding of this principle by continuing the arrow(s) for any transmitted color(s) and filling in the blanks in the following diagrams.



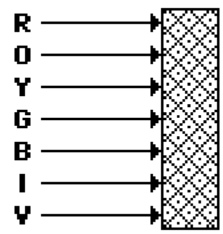
Pigment capable of absorbing ROYBIV

Appears __________



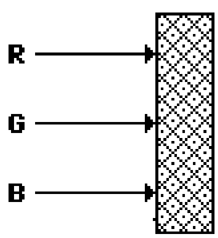
Pigment capable of absorbing ROYIV

Appears __________



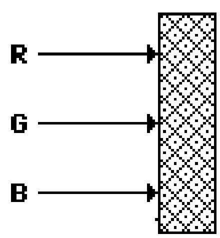
Pigment capable of absorbing YGBIV

Appears __________



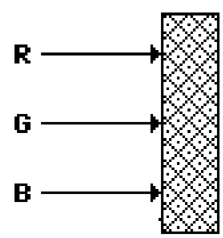
Pigment capable of absorbing R

Appears __________



Pigment capable of absorbing G

Appears __________



Pigment capable of absorbing OYGBIV

Appears __________

7. What color(s) of visible light will a cyan (bluish-green) pair of sunglasses ...
   a. ... transmit?

   b. ... absorb or block?

Color Addition and Subtraction

Read from **Lesson 2** of the **Light Waves and Color** chapter at **The Physics Classroom:**

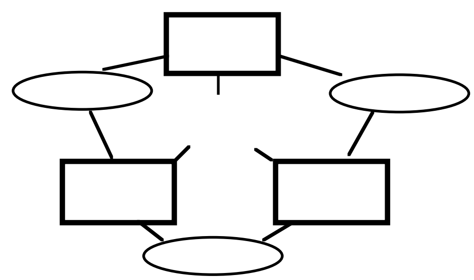
http://www.physicsclassroom.com/Class/light/u12l2d.html
http://www.physicsclassroom.com/Class/light/u12l2e.html

MOP Connection: Light and Color: sublevels 3 and 4

1. White light is observed when light of _______ wavelengths strike the retina.

2. Primary colors of light are three colors of light which when mixed together produce white light. There are many different sets of primary light colors. Interestingly enough, the eye contains three types of color sensors (nerve cells) which sense the entire span of the visible light spectrum. Each of the three types of cells sense a range of colors; yet they are most sensitive to a specific light color. The most common set of three primary light colors are those which correspond to the three colors which the nerve cells are most sensitive to. What are these three primary colors?

3. By combining pairs of these three **primary colors** in equal intensity, one can produce the secondary colors of light. State the pairs and the secondary colors they produce. Then fill in the color wheel to the right.

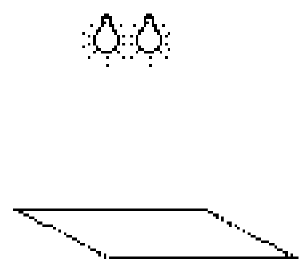


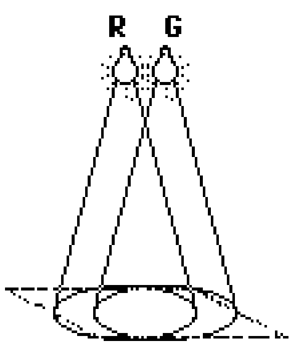
________________ & ________________ make __________ .

________________ & ________________ make __________ .

________________ & ________________ make __________ .

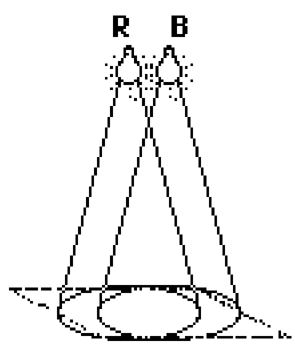
4. Two lights are arranged above a white sheet of paper. When the lights are turned on they illuminate the entire sheet of paper (as seen in the diagram at the right). Each light bulb emits a primary color of light - red (**R**), green (**G**), and blue (**B**). Depending on which primary color of light is used, the paper will appear a different color. Express your understanding of color addition by determining the color which the sheet of paper will appear in the diagrams below.





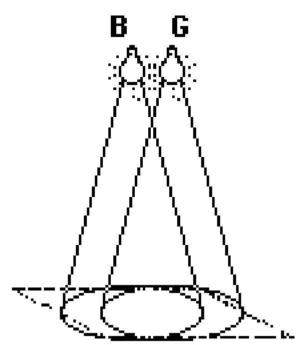
Paper appears

____



Paper appears

____



Paper appears

____

5. **Complementary colors of light** are combinations of two light colors which can be mixed together in equal intensities to produce white light. Thus, the complementary color of ...

   a. ... red light is ____________________ light.

   b. ... green light is ____________________ light.

   c. ... blue light is ____________________ light.

6. **The Rule of Color Subtraction:** An understanding of complementary colors assists in understanding the color appearance of objects when viewed under white light. Whenever an object subtracts a color from white light, it appears as the complementary color. If an object absorbs cyan light, then it will appear as red. Conversely, an object which appears as red is an object which absorbs cyan light. Use these ideas to complete the following statements.

   When viewed under white light (RGB), a ...

   a. ... red shirt will absorb ________________ light and reflect ________________ light.

   b. ... green shirt will absorb ________________ light and reflect ________________ light.

   c. ... blue shirt will absorb ________________ light and reflect ________________ light.

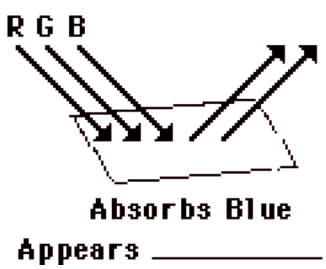
   d. ... cyan shirt will absorb ________________ light and reflect ________________ light.

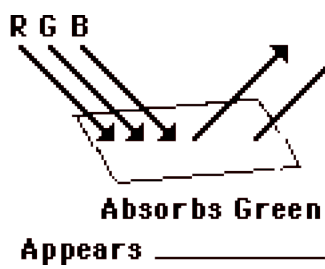
   e. ... magenta shirt will absorb ________________ light and reflect ________________ light.

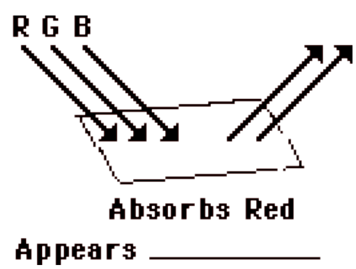
   f. ... yellow shirt will absorb ________________ light and reflect ________________ light.

   g. ... black shirt will absorb ________________ light and reflect ________________ light.

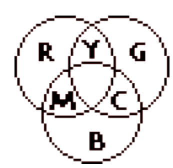
7. Express your understanding of complementary colors and the rule of color subtraction by completing the following three diagrams. White light (red-green-blue) is shown incident on a sheet of paper which is painted with a pigment which absorbs one of the primary colors of light. For each diagram, label the color of the two reflected colors and label the color which the paper appears.







8. The **mathematics of color** has little to do with numbers and much to do with the addition and subtraction of colors. The addition of two colors of light results in a new color. Use the *color wheel* at the right and the concept of complementary colors to complete the following *color equations*. (W = white; R = red; G = green; B = blue; C = cyan; M = magenta; Y = yellow)



a. R + G = ______	b. R + B = ______	c. G + B = ______
d. R + C = ______	e. G + M = ______	f. B + Y = ______
g. W - R = ______	h. W - G = ______	i. W - B = ______
j. W - C = ______	k. W - M = ______	l. W - Y = ______
m. W - R - C = ______	n. W - G - B = ______	o. W - M - G = ______

Viewed in Another Light

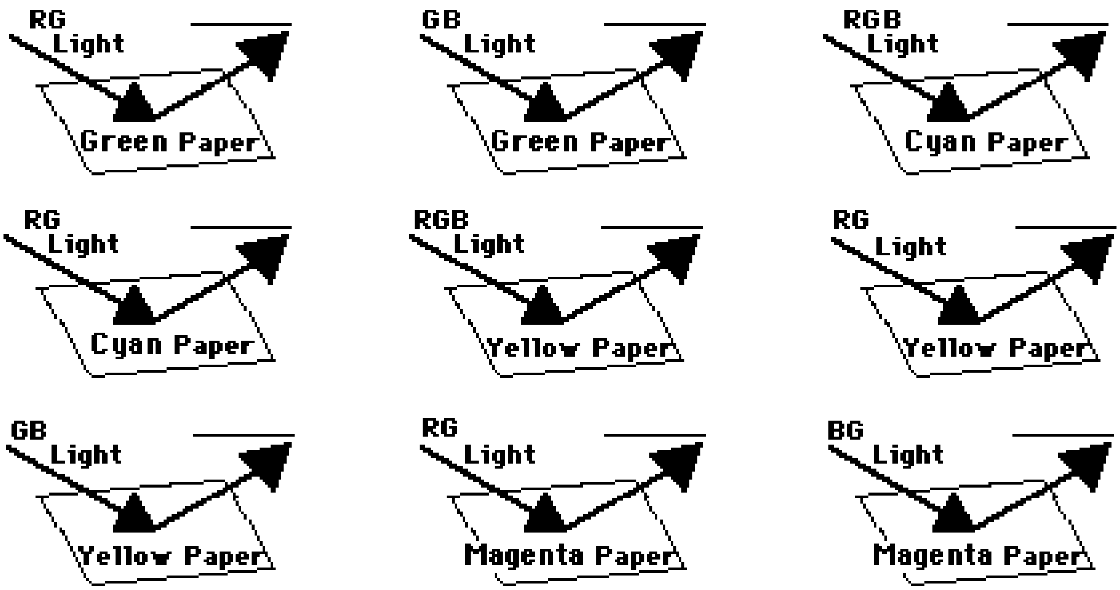
Read from **Lesson 2** of the **Light Waves and Color** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/light/u12l2d.html
http://www.physicsclassroom.com/Class/light/u12l2e.html

MOP Connection: Light and Color: sublevel 5

We are accustomed to viewing the world in *white* light. In effect, the light incident upon the objects we normally view can be simplified as a mixture of red, green and blue light (RGB). But the rules of color addition and subtraction are not limited by the restriction that white light is incident upon the object being viewed. After all, an object is often times illuminated by light other than white light. For example, theaters and concerts often illuminate the stage with red light or cyan light or any combination of two or more light colors. Determining the color appearance of such objects demands that you first identify what color(s) of incident light will be *subtracted* (i.e., absorbed), and then deduct the appearance of the object from those colors which are reflected.

1. In the diagrams below, several sheets of paper are illuminated by different primary colors of light (**R** for red, **B** for blue, and **G** for green). Indicate what primary colors of light will be reflected. (Note that *red paper* is defined as paper which appears red when viewed under white light.)



2. Different color light sources are shone on different colored sheets of paper. Consider which colors of light would reflect off the paper in order to determine the color which is observed.

	Light color	Paper color	Color observed
a.	Yellow	Green	
b.	Magenta	Blue	
c.	Cyan	Red	
d.	Yellow	Cyan	
e.	Magenta	Green	
f.	Cyan	Magenta	

Light and Color

As is obvious from the previous questions, the color appearance of an object is dependent upon the colors of light which are incident upon it. The color of an object is not actually within the object itself; rather, the color is in the light which shines upon it is ultimately reflected by it to our eyes. A *yellow object* does not always appear yellow. Suppose we were to restrict the discussion to some combination of red, green and blue primary light colors being incident upon the yellow object. As such, the yellow object only appears yellow when it reflects red and green light to our eyes. If either red and green light are NOT incident upon it, then the shirt will not appear yellow. Express your understanding of this by answering the following questions.

3. Name possible colors which a red shirt could appear when viewed under various combinations of red, green and blue spotlights.

4. Name possible colors which a yellow shirt could appear when viewed under various combinations of red, green and blue spotlights.

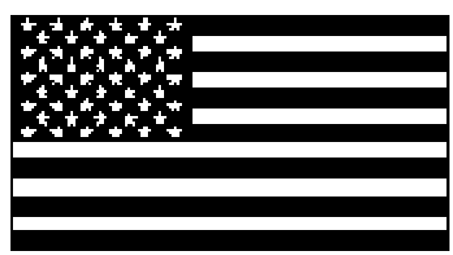
5. Name possible colors which a magenta shirt could appear when viewed under various combinations of red, green and blue spotlights.

6. Name possible colors which a cyan shirt could appear when viewed under various combinations of red, green and blue spotlights.

Three colored spotlights - red, green and blue - with equal intensities are turned ON and OFF to illuminate a shirt with different colors of light. A shirt which appears ________**(A)**____ when viewed in white light is placed under the spotlights and appears ____**(B)**_ This is conclusive evidence that the ____**(C)**____ spotlights are turned on and the ____**(D)**_____ spotlights are turned off.

	A Appearance in white light	**B** Appearance under unknown lights	**C** Spotlights which are ON	**D** Spotlights which are OFF
7.	Red	Red		
8.	Green	Green		
9.	Green	Black		
10.	Yellow	Red		
11.	Yellow	Green		
12.	Cyan	Cyan		
13.	Cyan	Blue		
14.	Magenta	Red		
15.	Magenta	Black		

16. If suddenly you were given a chemical which impaired the nerves in your eyes which detect red light, what color would a U.S. flag appear? Show this in the diagram by labeling the different parts.



Painting With CMYK

Overview:

It's your time to order uniforms for the school's football teams. There is one difficulty: the company which you will order from prefers to receive the order in terms of the three primary colors of paints which will be applied to different parts of the uniform. In this activity, you will experiment with the effect of different paint colors on the appearance of the various parts of a football team uniform.

Getting Started:

Open an Internet browser and navigate to the Painting With CMYK activity found in the Shockwave Studios section of the web site.

Directions:

Cyan, magenta, and yellow are the three primary colors of paint; Each paint color will absorb a single primary color of light. Investigate the result of adding (or mixing) these primary paint colors together by experimenting with the on-screen interface.

Finally, circle the primary paint colors which must be imparted to the following team uniforms in order to create the indicated color appearance:

Team #1: Chicago Titans

Uniform Part	Desired Color Appearance	Required Paint Colors
Helmet	Blue	**C M Y**
Skin	Magenta	**C M Y**
Shirt	Yellow	**C M Y**
Pants	Blue	**C M Y**
Socks	White	**C M Y**
Shoes	Black	**C M Y**

Team #2: Washington Knights

Uniform Part	Desired Color Appearance	Required Paint Colors
Helmet	Red	**C M Y**
Skin	Black	**C M Y**
Shirt	Blue	**C M Y**
Pants	White	**C M Y**
Socks	Red	**C M Y**
Shoes	Yellow	**C M Y**

Team #3: St. Louis Fliers

Uniform Part	Desired Color Appearance	Required Paint Colors
Helmet	Green	**C M Y**
Skin	Yellow	**C M Y**
Shirt	Green	**C M Y**
Pants	Yellow	**C M Y**
Socks	White	**C M Y**
Shoes	Black	**C M Y**

Follow-Up Questions:

1. Tell the result of mixing the following primary color of paints in equal amounts:

   Cyan + Magenta ----> ____________________ Cyan + Yellow ----> ________________________

   Magenta + Yellow ----> ___________________ Cyan + Magenta + Yellow ----> ______________

2. What primary paint colors must be imparted to an object to give it the appearance of white?

3. What primary paint colors must be imparted to an object to give it the appearance of black?

4. A primary paint color serves to selectively absorb a specific primary color of light. Whatever light is not absorbed is reflected by that paint. Use your understanding of color addition and subtraction to indicate which primary colors of light are absorbed by each primary paint.

   Cyan paint absorbs the primary light color ______________________________.

   Magenta paint absorbs the primary light color ___________________________.

   Yellow paint absorbs the primary light color _____________________________.

5. Complete the color equations shown below and indicate the primary paint color(s) in the object.

   a. R + G + B light - ____________ light = R + G light = ___________ appearance; there is ___________ paint in the object.

   b. R + G + B light - ____________ light = R light = ___________ appearance; there is ___________ paint in the object.

   c. R + G + B light - ____________ light = G + B light = ___________ appearance; there is ___________ paint in the object.

   d. R + G + B light - ____________ light = __________ light = Magenta appearance; there is ___________ paint in the object.

   e. R + G + B light - ____________ light = __________ light = Black appearance; there is ___________ paint in the object.

   f. R + G + B light - ____________ light = G light = ___________ appearance; there is ___________ paint in the object.

Pigments and Paints

Read from **Lesson 2** of the **Light Waves and Color** chapter at **The Physics Classroom:**

http://www.physicsclassroom.com/Class/light/u12l2d.html
http://www.physicsclassroom.com/Class/light/u12l2e.html

MOP Connection: Light and Color: sublevels 6, 7, and 8

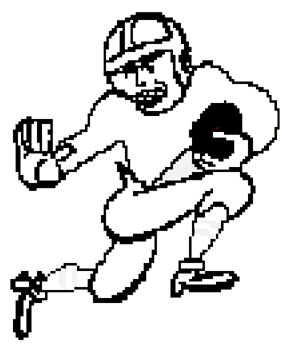
1. A **primary pigment** or paint is a chemical dye which is imparted to an object and is capable of absorbing a single primary color of light. The three primary pigments are cyan (C), magenta (M) and yellow (Y). By mixing these colors an artist can create any color by only having three different colors of paint. List the color of light which is absorbed by each of the primary paints.

   Magenta absorbs __________ Cyan absorbs ____________ Yellow absorbs __________

2. What paint colors could be used to paint a boy if he has pink (magenta) skin, blue jeans, a blue and yellow sweater, a black and white baseball cap, cyan socks and red sneakers? (Now that's "styling.")

Colors	Paint Colors
Pink skin	
Blue jeans	
Yellow part of sweater	
Black part of sweater	
Black part of cap	
White part of cap	
Cyan socks	
Red sneakers	

3. Suppose that you and a friend are starting to get a little carried away with your enthusiasm for the physics of color (a very understandable situation). Rather than seeking professional help, you begin discussing the colors of your favorite NFL team's uniforms in terms of the primary pigments which have been imparted to each item. What pigment colors must be imparted to each part of a uniform for it to appear as shown in the table below?



Uniform Part	Color Appearance	Imparted Pigments
Helmet	Yellow	
Shirt	Blue	
Pants	Yellow	
Socks	White	
Shoes	Black	

4. Color printers use the three primary pigments as ink colors in order to produce the range of colors on a colored image. Baxter Nachur recently completed his science report on the Birds of Brazil. The image at the right was included on his cover page. Identify the pigments which were used by the printer to create the ...

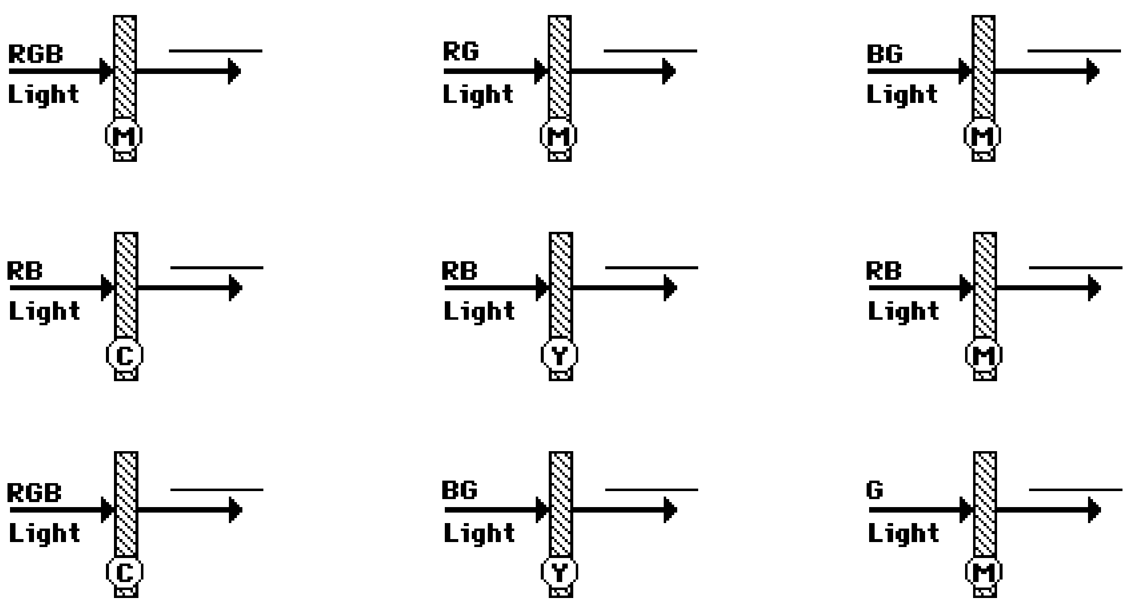
   a. ... red wings: ______________ b. ... cyan breast: ______________

   c. ... blue body: ______________ d. ... green tail: ______________

5. In a very colorful physics demonstration, Mrs. Claire Voyance uses three colored spotlights - red, green and blue - with equal intensities to illuminate a sheet of paper with different colors of light. Before turning the spotlights on, she paints the paper with various combinations of primary pigments. She then asks her students to predict in advance the color(s) of light that the paper will absorb and the color that the paper will appear. Use your understanding to make the same prediction.

	Spotlights Which Were Turned On	Pigments Applied to Paper	Light Colors Absorbed	Color Appearance
a.	R, G, and B	C		
b.	R, G, and B	C and M		
c.	R and B	C and M		
d.	R and B	C and Y		
e.	R and G	M and Y		
f.	R and G	Y		
g.	G and B	C and M		
h.	G and B	M and Y		
i.	G	C and Y		
j.	B	Y		

6. Opaque objects imparted with pigments selectively absorb light and reflect whatever light colors are not absorbed. Filters are transparent materials which selectively absorb (or block) one or more primary colors of light and allow the remaining colors of light to pass through (or be transmitted). The color of the filter describes which color of light is transmitted by the filter. The following diagrams depict various primary colors of light (**R** for red, **B** for blue, and **G** for green) incident upon a colored filter (**C** for cyan, **M** for magenta, and **Y** for yellow). Determine which primary colors of light will pass through the filters.



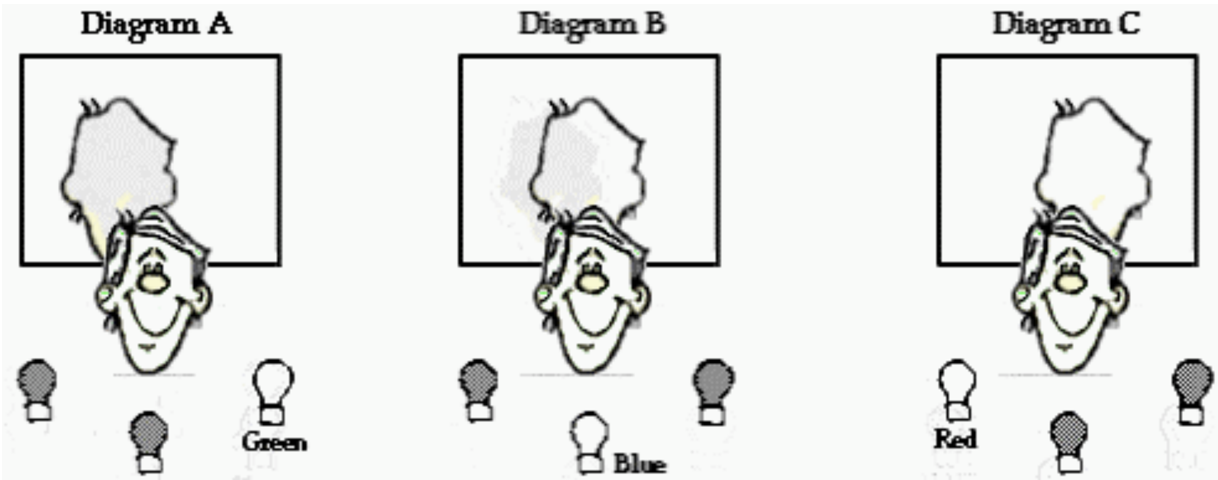
Shadows

Read from **Lesson 2** of the **Light Waves and Color** chapter at **The Physics Classroom:**

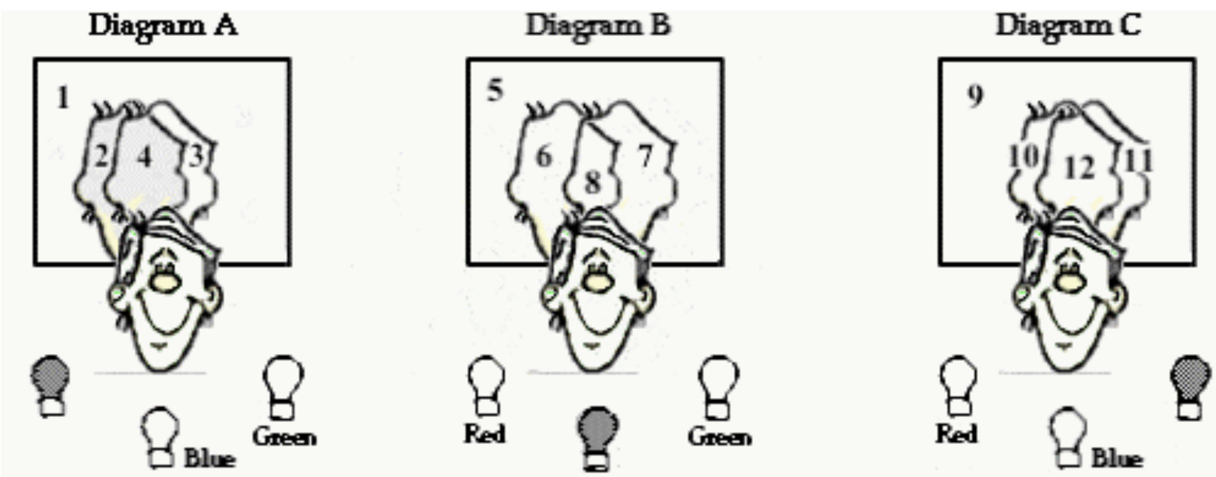
http://www.physicsclassroom.com/Class/light/u12l2d.html
http://www.physicsclassroom.com/Class/light/u12l2e.html

MOP Connection: Light and Color: sublevel 9

1. A shadow is created when light from a source is blocked by an object, thus preventing that light from illuminating a screen. In the diagrams below, a teacher is blocking the light which is shining towards the whiteboard. Label the color of the shadow and the color of the whiteboard.



2. Now the same teacher stands in front of two lights, thus casting two shadows on the whiteboard. To complicated matters, the two shadows overlap in the middle wherever both lights are being blocked and prevented from hitting the whiteboard. Express your understanding by identifying the colors of the labeled regions.

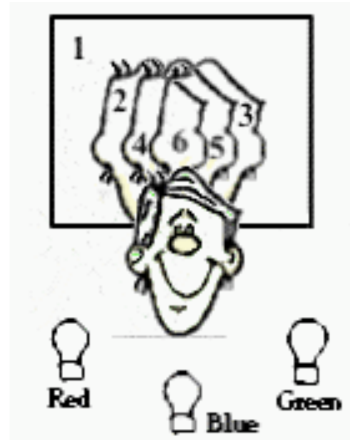


Part #	Color
1	
2	
3	
4	

Part #	Color
5	
6	
7	
8	

Part #	Color
9	
10	
11	
12	

3. Now the teacher stands in front of three lights, thus casting three shadows on the whiteboard. And of course the three shadows overlap in various ways, creating an intricate pattern on the whiteboard. Express your understanding by identifying the colors of the labeled regions.



1 = ________________________________

2 = ________________________________

3 = ________________________________

4 = ________________________________

5 = ________________________________

6 = ________________________________