27 Color

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Carlos Vasquez colorfully opens this chapter with the three-lamp demo. Carlos's dad is John Vasquez, one of the five Vasquez brothers who took my class in consecutive years back in the 70s and 80s. All are now educators. Some twenty years ago I boasted that Suzanne Lyons Lange was the best of my editors with Addison-Wesley. Since then she advanced through the ranks and I'm presently delighted to have her as a co-author to my physical science books! She is shown here with her children, Tristan and Simone. Photo five is of Jeff Wetherhold who brings color not only to his classroom, but to canvas. Jeff's passion for physics is evident in his website (www.parklandsd.org/web/wetherhold/). Between the Vasquez and Lange family, and Jeff Wetherhold, what a great group of people!

The brief profile is of Isaac Newton and his investigations of color.

In this chapter we introduce a model of the atom in which electrons behave as tiny oscillators that resonate or are forced into vibration by external influences. If you haven't preceded light with a study of sound, and if you haven't demonstrated resonance with a pair of tuning forks, do it now, for the tuning fork model is used in the text to account for selective reflection and transmission of light.

We continue to refer to color primarily by frequency rather than wavelength, in effort to reduce the number of terms students must learn to understand concepts. Wavelength is now measured in nanometers for the color spectrum, probably because there seems to be evidence that the color sensitive elements of the retina-optic-nerve-brain system are more reasonably a function of wavelength than frequency due to velocity variation. There is a trend to terahertz (THz) in place of exponential notation for visible light frequencies.

Titanium dioxide makes up white pigments used for nearly all things that are white.

The conure shown in Figure 27.13, for what it's worth, is the pet bird of my wife Lillian.

Be sure to mount three floodlights on your lecture table, red, green, and blue, of shades such that all three overlapping produce white on a white screen, as shown in the chapter opener photograph of Carlos Vasquez. Then stand in front of the lamps, illuminated one at a time and show the interesting colors of the shadows, as shown by the shadows of the golf ball in Figure 27.10 (photographed, by the way, by Carlos's Uncle David Vasquez). Impressive!

Do as Lew Slack does at Christmas time and shine three lights on your white door—red, green, and blue. Guests who come to the door are quite impressed with the colored shadows!

Arbor Scientific has a 3-lamp apparatus (P2-9700) that lets you project colored circles on a screen or wall. You can adjust the intensity of each spotlight. Their Light Box and Optical Set (P2-9561) is also impressive.

After the suggested lecture below, I'm including a special lecture that is appropriate not only for your class, but for a general audience. If you're ever asked to do a science demonstration for a general audience, they'll be thrilled by this one. Go for it! To do it you'll need the three colored lamps and rheostats to vary their brightness.

This interesting chapter is not a prerequisite to chapters that follow.

Practicing Physics Book:
- Color Addition (overlapping primary colors producing shadows)

Next-Time Questions:
- Colored Shadows

Hewitt Drew It! Screencasts: •*Color* •*Why the Sky is Blue*

SUGGESTED LECTURE PRESENTATION

Selected Reflection

Discuss the oscillator model of the atom, and the ideas of forced vibration and resonance as they relate to color, as you display different colored objects. A red object, for example, reflects red. It absorbs the other colors. Resonance is *not* occurring for red, by the way, for the resonant frequencies are being *absorbed*. (I was confused about this point for years!) Recall the absorption of resonant frequencies in the treatment of transparency in Chapter 26.

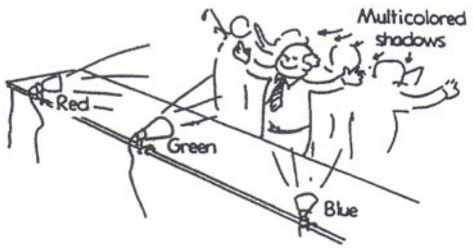
Selective Transmission

Similarly for colored glass—the resonant frequencies are absorbed and becomes the internal energy of the transparent material. The frequencies to pass through the glass are those away from the resonant frequencies. Frequencies close to resonance undergo more interactions with the molecules and take longer to travel than frequencies far from resonance. Hence different colors have different speeds in transparent materials. (If not, then no rainbows, as we shall see!)

Mixing Colored Light

The colors in the rainbow combine to white, but red, green, and blue do the same. You can show that in a variety of ways. The Arbor Scientific 3-lamp apparatus described earlier is one.

> DEMONSTRATION: Show the overlapping of the primary colors with a 3-lamp demo. Show complementary colors, and discuss the rule of color mixing.
>
> DEMONSTRATION: If you haven't shown your class the black hole that appears in a box with white interior, back in the heat chapter (Chapter 16 opener photos) do it now. It nicely illustrates the "color" black.
>
> DEMONSTRATION: This is a must! Show the overlapping of light from three lamps on your lecture table aimed at a white screen behind you. The variety of colors in the shadows of you are very impressive. And their explanation by showing only the black shadow from one lamp, then two lamps where the black shadow is now the color of the second lamp, and then three lamps with explanation, is quite satisfying. (A complete narration to accompany this demonstration, suitable for general audiences, is at the back of this suggested lecture.) Carlos Vasquez shows this in the photo that opens this chapter.



DEMONSTRATION: Do as Chris Chiaverina does and attach to an electric drill three chemical tubes that glow red, green, and blue when activated. When spun they combine to a white light. When a piece of tape covers a part of each, in turn, the complementary color is seen. Quite impressive in a darkened room.

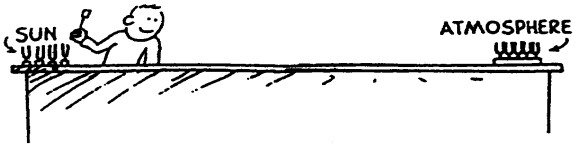
Why Water is Greenish Blue

Water absorbs infrared. It also absorbs visible light up into the red end of the color spectrum. Take away red from white light and you are left with the complementary color—cyan. A piece of white paper deep in the water looks cyan. There is no red left in the sunlight to make it white. A red crab and a black crab have the same appearance on the ocean floor.

Why the Sky is Blue

Compare the molecules in the atmosphere to tiny bells, that when struck, ring with high frequencies. They ring mostly at violet, and next at blue. We're better at hearing blue, so we hear a blue sky. On the other hand, bumblebees and other creatures that are good at seeing violet see a violet sky.

LECTURE SKIT—PART 1; Blue sky: (You can see this on my video *Why the Sky is Blue.*) Put a variety of six tuning forks at one end of your lecture table—a "red" one, "orange" one, "yellow" one, etc., to a "violet" one. Ask what "color" sound they would hear if you struck all the tuning forks in unison. Your class should answer, "White." Then suppose you have a mirror device around the forks so that when you "strike" them again, a beam of sound travels down the length of your lecture table. Ask what color they will hear. Several might say "White" again, but state that if there is no medium to scatter the beam that they will hear nothing (unless, of course, the beam is directed toward them). Now place a tray of tuning forks at the opposite end of your lecture table (the tray I use is simply a 2 by 4 piece of wood, about a third meter long, with about a dozen holes drilled in it to hold a dozen tuning forks of various sizes). Ask your class to pretend that the ends of your lecture table are 150 million km apart, the distance between the Earth and the Sun.



State that your tray of assorted tuning forks represents the Earth's atmosphere—point to the tuning forks, calling out their colors; a blue one, a violet one, a blue one, a blue one, a red one, a blue one, a violet one, a blue one, a green one, a blue one, a violet one, and so forth emphasizing the preponderance of blue and violet forks. Your tray of forks is perpendicular to the imaginary beam from the Sun (to simulate a noonish thin atmosphere). Walk to the Sun end of the table and again pretend to strike the forks and show how the beam travels down the table and intercepts and scatters from the atmospheric tuning forks in all directions. Ask what color the class hears. And you have a blue sky, especially if they're a bit deficient in hearing violet.

Why Sunsets are Red

PART 2; Red sunset: Sketch a rendition of Figure 27.18 on the board and show that at sunset the sunlight must travel through many kilometers of air to reach an observer—that blue light is scattered all along these kilometers. What frequencies survive, you ponder. Then back to your Sun and Earth forks on the lecture table. It is important to rotate the tray of forks 90° to represent the Earth's thicker atmosphere at sunset. Select a student (a cooperative one, of course) from the class to sit beside the tray of Earth forks. State to the class that your volunteer represents an Earth observer at sunset. Go back to the Sun forks which you pretend to strike. Down the table comes the beam, which you follow. Whap, into the

> Earth's atmosphere where most of it scatters throughout the classroom. Again, ask the class what color they "hear." "Blue" is the answer. Correct. Now you ask your volunteer what color he or she heard. "Orange," is the answer! Your demonstration has been a success. For humor, by "experiment" you have proved your point. Your student volunteer has simply heard a composite of the lower-frequency leftover colors after the class received most all the higher-frequency blues. So those nice colors at sunset are what? Leftover colors.

Put another way, you can say the orange of the sunset is the complementary color of the blue-violet sky.

> DEMONSTRATION: Back to the three-lamps demo. With the three lamps fully illuminated to produce white on the screen, gradually turn down the blue and the screen turns yellow, and then turn the green lamp down a bit to produce an orange—the color of the sunset. Very impressive! Don't turn the green all the way down—save this for the red color of the eclipsed Moon.

Why the Moon is Red During a Lunar Eclipse

This is featured as a Chapter 28 Next-Time Question in the NTQ book. Return to your three-lamps demo. Begin with all lamps fully illuminated to produce white. Then turn down the blue and green lamps, gradually, until all that's left on the screen is red. This is what occurs when all the higher frequencies (green as well as blue) are scattered, leaving only the red to refract through the "lens" of the Earth's atmosphere to shine on the eclipsed Moon. Again, most impressive!

Why Clouds Are White

Small particles scatter high frequencies. Larger molecules and particles also scatter lower frequencies (like larger bells ring at lower frequencies). Very large ones ring in the reds. In a cloud there are a wide assortment of particles—all sizes. They ring with all colors. Ask your class if they have any idea why clouds are white! (Cumulus clouds, composed of droplets, are white because of the multitude of particle sizes, but higher-altitude cirrus clouds are composed of ice crystals, which like snow, reflect all frequencies.)

> DEMONSTRATION: (An alternate to the above sequence.) Shine a beam of white light through a colloidal suspension of a very small quantity of instant nonfat dry milk in water, to show the scattering of blue and transmission of orange. (Dean Baird does this at the bottom of page 513.)

Discuss the blueness of distant dark mountains and the yellowness of distant snow-covered mountains (as discussed in the Check Yourself questions in the text).

Mixing Colored Pigments

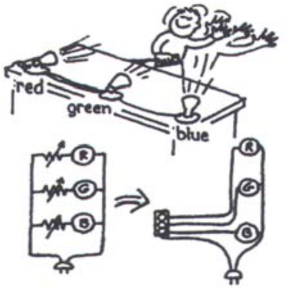
Now we address color mixing as it relates to early finger painting experience (blue + yellow = green; red + yellow = orange; red + blue = purple). This was likely the only color mixing information encountered by your students prior to this chapter. (I have never lectured about this material in detail, and have left it to the students' reading.)

Pass a magnifying glass around and look at the cyan, magenta, and yellow dots that make up the colors of photos in the book.

Retina fatigue

Looking for a long time at a strong color causes cone fatigue. If the eye then looks at a white surface, there is a strong afterimage of the complementary color. Surgeons stare intently for long periods of time at scenes that appear bright (blood) red under bright lights. The red photoreceptors in the eye thus become fatigued. If the surgeon looked at assistants in white suits, disturbing afterimages would occur. This effect is counteracted by blue, green, or cyan scrub uniforms, that result in an unnoticeable afterimage.

Special Lecture/Demo on Color Light Addition



This narration with three colored lamps, red, green, and blue, each a meter or so apart in front of a white surface, is great for a general audience. The narrator holds dimmer switches for each lamp and has an assistant stand between the lamps and screen. The narrator can stand in the light, but if it's a classroom, students like to see "one of their own" in the light for a change. Although dichro-color flood lights are quite vivid, any red, green, or blue flood lamps, or even colored gels in front of white lamps, works fine. Common wall-switch dimmers vary brightness. [*Wiring diagram is as shown.*]

White light from the Sun or an incandescent lamp is composed of the spectral colors. The reds are the lowest frequencies, the greens the middle, and the blue and violet the highest. Color vision is the result of three types of cones sensitive to the three colors, red, green, and blue. Color television uses combinations of only these three primary colors to produce the color spectrum. Note the white light where the red, green, and blue lamps overlap.

[Project all three lamps at once on the screen to show white.]

Let's look at these colors one at a time.

[Project red on screen; then green.]

Note that red and green overlap to produce yellow. Is that surprising? What is the average of red + green? What's between red and green in the spectrum? Yellow! So red light and green light produce yellow light.

[Project blue atop red and green.]

And all three produce white light.

[Person walks into the crossed beams.]

Note that she is illuminated just as if white light was shining upon her. You can't tell the difference—except for the shadows! Where the colors overlap, different colors are produced. Can these colors be understood? Yes they can, if we look at their role one at a time.

[Shine only red light and step into beam.]

Note that both the person and the screen is red. But the shadow is black. Black, strictly speaking, isn't a color. It's the absence of light. And the shadow region is a region with no light—so it's dark. No mystery here. But watch the color of the black shadow when I turn on the green light.

[Turn on green light, so red and green are on.]

Note that the black shadow is now green. That makes sense. Green light is falling on the formerly dark area. And note that the green light casts a shadow. If the red light weren't here, what color would it be?

[Turn off the red light so black shadow from green lamp appears.]

[Turn back the green so red and green shine.]

No color! Black. So we see the shadow from the green lamp is red because red light shines on it.

No mystery here. And look at the background—yellow. As we expect from the average of red + green. Now let's focus our attention to one of these shadows, say the red one when I turn on the blue.

[Turn on the blue, so all three are shining.]

We see the red shadow turns a different color—the average of red + blue—**magenta**—bluish **red**—the color of Bougainvillea blossoms! And look at the former green shadow. With blue added, it's now a bluish green—**cyan**—the color of tropical seas. And we see a third shadow, the one cast by the blue lamp. It's not black because there are two colors shining on it. We see the color is **yellow**. Why is the color of this shadow yellow? In other words, what are the colors that shine on the shadow produced by the blue lamp? Check your neighbor!

We've seen that red, green, and blue overlap to produce white light. We call these three colors the **additive primary colors**. The three types of cones in our retinas are sensitive to these colors.
Question time: Is it possible for *two* colors to produce white?

Will red + green = white? No, we've seen that red + green = yellow.
Will green + blue = white? No, we've seen that green + blue = cyan.
Will red + blue = white? No, we've seen that red + blue = magenta.
Is there some other color that when combined with red = white? Check your neighbor!

The answer is cyan. And why not, for cyan, after all, is the combination of green + blue. So cyan + red = white. Colors are logical.

We call any two colors that add to produce white, **complementary colors**. We say red and cyan are complementary colors. Put this algebraically: red + cyan = white.
Question: By the same algebra, what is white-red? Check your neighbor! Let's try it.

[Turn down the red light from the overlapping three, and leave cyan.]

This brings us to some interesting physics. Water is a strong absorber of infrared radiation—that's light with a lower frequency than red. Different materials absorb different frequencies of light, which is why we see so many different colors around us. It turns out that water not only absorbs infrared, but also absorbs visible red. Not a lot, which is why a glass of water appears without color. But the red absorbed by a larger body of water, like the ocean, means that when white light from the Sun shines on it and is reflected, some of that white light isn't there anymore. The red is absorbed, which is why the ocean is cyan. A white piece of paper near the surface of water still looks white because only a little bit of red is absorbed by the time it reaches the paper. But if the white paper is deeper, it looks greenish blue. If it's very deep, it's a vivid greenish blue—cyan. Sunlight that reaches the bottom of the sea has no more red in it. A lobster that looks red at the surface, looks black at the bottom, for there is no red light to show its redness. At the bottom of the sea, a red-painted object and a black-painted object look alike.

We have a nearly white Sun because it emits all the visible frequencies. The distribution of frequencies is not even, however, and since more red is emitted than violet, the Sun is a yellowish white. But the sky is blue. Why is the sky blue? Well this is another story; let's discuss the short version.

When sunlight hits the molecules in the Earth's atmosphere, light is **scattered**. Have you ever seen the demonstration where sound is scattered off a tuning fork? When you hit one fork and the sound travels across the room and interacts with another tuning fork of the same frequency, what happens? The answer is, the second fork is set into vibration. In a sense, it *scatters*, the sound from the first fork. The same demonstration can be done with bells. Tuning forks and bells scatter sound. Molecules similarly scatter light waves—at select frequencies. Everything has its own natural frequency. Consider two bells—a large one and a small one.

If we strike the large one it goes “bong.” If we strike the small one it goes “ting.” We all know, that large bells ring with low frequencies, and tiny bells ring with high frequencies. Similarly with light waves. Small molecules, or small particles, scatter high frequencies; large particles scatter low frequencies. So what is the atmosphere composed of? Tiny molecules. And what color of sunlight do these tiny particles scatter? High-frequency; blue! So we have a blue sky.

We look at the clouds and they are white. What does this indicate about the size of particles making up a cloud? Check your neighbor! The answer is, an assortment of particle sizes. Different particle sizes scatter different colors, so the whiteness of a cloud is evidence of a wide variety of particle sizes. If white light falls on a cloud, it looks white. If the particles grow so that they absorb rather than reflect light, then the cloud is dark—and we have a rain cloud.

Now at sunset, or sunrise, clouds are not white. Even the Sun is not white. The Sun is reddish yellow—orange—low frequency light. Why is the Sun this color? Watch what happens when I subtract the higher frequencies from white light.

[From the three shining lamps, turn down the blue lamp.]

All the blue is gone. The white light has turned yellow. If the atmosphere is thick enough, some of the greens are scattered as well.

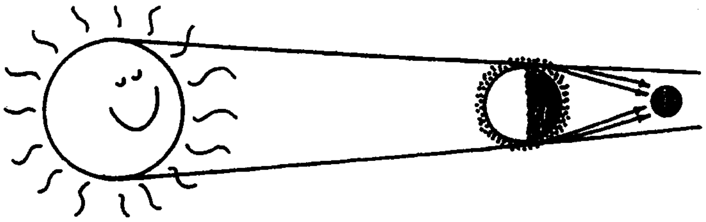
[Turn down the green lamp, but not all the way.]

And we have a yellowish red—the color of sunsets. The passage through the atmosphere at sunset is not long enough to scatter all the mid-frequencies, so we don’t normally see the Sun as a deep red. But there is an event where only a deep red survives atmospheric scattering. And that happens during the **eclipse of the Moon**.

Exactly what is happening during a lunar eclipse? The Earth casts a shadow on the Moon. [Show via overhead projector or chalkboard (if you have either) how Earth is between Sun and Moon, and show the lens effect of the Earth’s atmosphere—how rays of light refract through the Earth’s atmosphere and cast upon the Moon. So the Moon is not completely dark. The small amount of light that falls on it has traveled through twice as much air as one sees at sunset, so all the blues and greens are scattered. The result? A deep red!]

[Turn the green lamp off, leaving only red on the screen.]

So poetically enough, the redness of the Moon is the refracted light from all the sunups and sunsets that completely circle the Earth!



Solutions to Chapter 27 Exercises

Reading Check Questions

1. Blue light has a higher frequency than red light.
2. The electrons are forced into vibration.
3. When light falls on a material with a matching natural frequency it is absorbed.
4. When light falls on a material with a natural frequency above or below the frequency of incoming light it is reemitted.
5. Red light is transmitter through red glass.
6. A pigment selectively absorbs light.
7. A colored piece of glass absorbs light and warms more quickly.
8. Light passing through a prism is separated into all the colors of the rainbow, and when recombined produce white light.
9. Peak frequency of sunlight is yellow-green.
10. Our eyes are most sensitive to yellow-green.
11. A radiation curve is a plot of brightness vs frequency for light.
12. Red, green, and blue occupy the full range of frequencies visible to the eye.
13. These three of equal brightness add together to produce white.
14. The resulting color is yellow.
15. Red and cyan add to produce white.
16. Cyan is the color most absorbed by red paint.
17. The three subtractive primaries are cyan, yellow, and magenta (CYM).
18. The colors are magenta, yellow, and cyan.
19. Small bells better interact with high-frequency sounds.
20. Small particles better interact with high-frequency light.
21. The sky normally appears blue because the blue end of the spectrum is scattered most by sunlight.
22. Light of lower frequencies is scattered by particles larger than oxygen and nitrogen molecules are in the atmosphere, producing a whitish sky.
23. Scattering of high-frequency blue light occurs all along the path of sunlight, so the long path at sunrise or sunset finds much blue missing. What remains is light of lower frequencies, which accounts for the reddish color of the Sun at these times. At noon the path through the atmosphere is shorter and less scattering occurs.
24. The colors vary because the atmospheric particle in the atmosphere vary.
25. A cloud is white because it reflects all the colors of sunlight equally.
26. Large droplets absorb light and the cloud becomes darker.
27. Infrared light is most absorbed by water.
28. Red light is mostly absorbed.
29. When red is subtracted, the result is cyan.
30. Water appears cyan because red light has been absorbed by the water.

Think and Do

31. Try this with the American flag!
32. Try this with youngsters!
33. This will be fascinating to skeptics!
34. Can you convince her that knowledge adds, not subtracts, from nature appreciation?

Think and Explain

35. Red has the longest wavelength; violet has the shortest wavelength.

36. Black is the absence of light. White can be formed by the combination of all spectral colors of light.

37. The interior coating absorbs rather than reflects light, and therefore appears black. A black interior in an optical instrument will absorb any stray light rather than reflecting it and passing it around the interior of the instrument to interfere with the optical image.

38. They are most likely to be noticed if they are yellow-green. That is where the eye is most sensitive. (See Figure 27.7.)

39. Tennis balls are yellow green to be more visible, where they match the color to which we are most sensitive.

40. Red cloth appears red in sunlight, and red by the illumination of the red light from a neon tube. But because the red cloth absorbs cyan light, it appears black when illuminated by cyan light.

41. A piece of paper that appears white in sunlight has the property of reflecting any color that is incident upon it.

42. The color that will emerge from a lamp coated to absorb yellow is blue, the complementary color. (White - yellow = blue.)

43. If the yellow clothes of stage performers are illuminated with a complementary blue light, they will appear black.

44. Color television employs color addition. White is the mixture of red, blue, and green, and black is an absence of light (actually the color of the blank screen). Yellow is produced by illumination of green and red dots, while magenta is produced by illumination of red and blue dots.

45. Red and green produce yellow; red and blue produce magenta; red, blue, and green produce white.

46. The colors used are cyan, yellow, and magenta. Black is also used. Colors are formed by color subtraction.

47. The orange-yellow is complementary to blue, which combine to black. Cars would be difficult to see under such light.

48. Blue illumination produces black. A yellow banana reflects yellow and the adjacent colors, orange and green, so when illuminated with any of these colors it reflects that color and appears that color. A banana does not reflect blue, which is too far from yellow in the spectrum, so when illuminated with blue it appears black.

49. Purple is seen. See Figure 27.12.

50. The red is absorbed by the water, enough to make a visible difference with slightly reddened feet. Try it and see.

51. Deep in water red is no longer present in light, so blood looks black. But there is plenty of red in a camera flash, so the blood looks red when so illuminated.

52. Yellow light + blue light = *white* light.
Green light + *magenta* light = white light.
Magenta light + yellow light + cyan light = *white* light.

53. Green + blue = cyan = white - *red*.

54. Agree, for the “light mathematics” is correct.

55. The reflected color is white minus red, or cyan.

56. Ultraviolet light is reflected by the sand, so although you are not in direct light, you are in indirect light, including ultraviolet. Also, just as visible light is scattered by particles that make up the atmosphere, ultraviolet radiation is scattered even more. So you can get a sunburn in the shade—by both reflection and scattering. (Years ago the author was quite sunburned while sitting in the shade of a mangrove tree at a sandy beach brainstorming exercises for this book! I learned this one the hard way.)

57. Such glasses eliminate the distraction provided by the more strongly scattered blue and violet light yet let the pilot see in a frequency range where the eye is sensitive. (Glasses that transmit predominantly red would also get rid of the scattered blue and violet light but would provide light to which the eye is not very sensitive.)

58. Light travels faster through the upper atmosphere where the density is less and there are fewer interactions with molecules in the air.

59. Agree.

60. Particles in the smoke scatter predominantly blue light, so against a dark background you see the smoke as blue. What you see is predominantly light scattered by the smoke. But against the bright sky what you see is predominantly the sky minus the light that the smoke scatters from it. You see yellow.

61. The statement is true. A more positive tone would omit the word "just," for the sunset is not *just* the leftover colors, but *is* those colors that weren't scattered in other directions.

62. An orange sky indicates preferred scattering of low frequencies. At sunset when the scattering path is longer, very little low-frequency light would get to an observer. The less-scattered high frequencies would produce a bluish sunset.

63. Through the volcanic emissions, the Moon appears cyan, the complementary color of red.

64. When reflection is dominant in clouds, sunlight is reflected evenly by color and the clouds are white. When absorption is dominant, the clouds are dark.

65. The foam is composed of tiny bits of liquid that scatter light as a cloud does.

66. Rain clouds are composed of relatively big particles that absorb much of the incident light. If the rain clouds were composed only of absorbing particles, then the cloud would appear black. But its mixture of particles includes tiny high-frequency scattering particles, so the cloud is not completely absorbing, and is simply dark instead of black.

67. If the atmosphere were several times thicker, the sunlight reaching the Earth would be predominantly low frequencies because most of the blue light would be scattered away. Snow would likely appear orange at noon, and a deep red when the Sun is not directly overhead.

68. If Jupiter had a semi-transparent atmosphere, the sun would not appear white. Molecules in the atmosphere would absorb some colors more strongly than others, producing a colored sun. In fact, there is a thick cloud cover in Jupiter's atmosphere that blocks all sunlight from reaching its "surface." And it doesn't have a solid surface!

69. Sunset follows the activities of humans and other life that put dust and other particles in the air. So the composition of the sky is more varied at sunset.

70. The water is broken up into a multitude of different size droplets when the wave breaks, and like the droplets in clouds overhead, light of many visible frequencies is scattered to produce the white color.

Think and Discuss

71. The customer is being reasonable in requesting to see the colors in the daylight. Under fluorescent lighting, with its predominant higher frequencies, the bluer colors rather than the redder colors will be accented. Colors will appear quite different in sunlight.

72. Red paint is red because it reflects the red component of white light, while absorbing the other components, particularly red's compliment cyan.

73. The red petals of a red rose will reflect red light while the green leaves absorb red light. The energy absorbed by the leaves tends to increase their temperature. White material reflects radiation and is therefore worn by those who do not wish to be warmed by absorbing radiant energy.

74. Either a white or green garment will reflect incident green light and be cooler. The complementary color, magenta, will absorb green light and be the best garment color to wear when the absorption of energy is desired.

75. We see not only yellow green, but also red and blue. All together, they mix to produce the white light we see. And due to atmospheric scattering the Sun is yellowish.

76. If only blue light gets through the blue filter, and only yellow gets through the yellow filter, the overlapping beams will produce white light. When the two panes of glass are overlapped and placed

in front of a single flashlight, however, little or no light will be transmitted, or some green depending on the range of colors getting through the filters.

77. Agree, for the “light mathematics” is correct.

78. The red shirt in the photo is seen as cyan in the photographic negative, and the green shirt appears magenta—both complementary colors. When white light shines through the photo negative, red is transmitted where cyan is absorbed. Likewise, green is transmitted where magenta is absorbed.

79. You see the complementary colors due to retina fatigue. The blue will appear yellow, the red cyan, and the white black. Try it and see!

80. We cannot see stars in the daytime because their dim light is overwhelmed by the brighter skylight, which is sunlight scattered by the atmosphere. However, a rare supernova (exploding star) is bright enough to be seen in a daytime sky.

81. At higher altitudes, there are fewer molecules above you and therefore less scattering of sunlight. This results in a darker sky. The extreme, no molecules at all, results in a black sky, as on the Moon.

82. The daytime sky is black, as it is on the nighttime sky there.

83. As seen from the surface of the Moon, both the Sun and the stars are clearly visible. This is because there is no skylight (scattered sunlight) to overwhelm the starlight.

84. The color of the Sun is yellow-white at all times on the Moon.