Today, you have a lot to learn about colors, from why blue and yellow don’t make green, to why the earth’s sky is blue and the moon’s sky is black. Let’s start our study of colors with a prism. Isaac Newton did his first experiments with one. He passed a narrow beam of white light through a prism and saw that a rainbow of colors was produced. He called this a spectrum. Let’s see how a prism separates light into the colors of the visible spectrum.

(prism on screen)

Refraction also allows us to divide what appears to be white light into its component colors. Rainbows are formed when sunlight is refracted through millions of water droplets, acting like prisms. When sunlight or incandescent light is passed through a prism, a spectrum of color is produced.

(diagram on screen)

Let’s start with a ray of red light, passing obliquely from air to glass and refracting. Because light travels slower in glass, the light will bend toward the normal. Then it travels to the other side of the glass, and passes through to the air, which is a faster medium. So it bends away from the normal.

Now, if violet light enters the prism along the same path, it also will bend toward the normal. But we find that the higher frequency violet light bends more than the red. So the violet light comes out here.

And what Isaac Newton found was that when white light enters the prism, red and violet and all the colors between will fan out as a spectrum of frequencies.

White light is a combination of all colors of the visible spectrum.

So white light coming from a light bulb or from the sun can be separated into the colors of the rainbow.

And speaking of rainbows, aren’t they beautiful sights? When do you usually see them? Tell your teacher.

Most of you probably said that it has to be raining or just stopped raining, so there’s a lot of moisture in the sky. And did you remember that the sun has to be shining? You’re right. One more thing. You must be standing with your back to the sun so that white light from the sun is coming over your shoulder toward the water drops in the sky in front of you.

Did you know that you could make an artificial rainbow? All you need is sunlight coming over your shoulder. You can add the moisture with a fine mist from a garden hose. Now watch this to get the details of how rainbows form.

(diagram on screen)

Rainbows are the result of the refraction of sunlight in billions of little water droplets. Each drop acts as a tiny prism, separating the white light into its colors. Get this in your notes.
The sun is back here, over your shoulder, and the rays of light will be coming in parallel to this one ray. When the white light goes from air into the water, it refracts. This shows only the red light. Now when the light hits the back of the drop, of course, some will pass through but some will turn around and be reflected. It will bend again as it leaves the drop, so the water acts like a kind of prism. The angle between the incident wave and the red light coming toward your eye is 42 degrees.

Since violet light bends more, the angle for it will be smaller: 40 degrees. So if you’re standing here, which color of light coming from this particular water drop will you be able to see? The red light will hit your eye. But remember that there are billions of water drops in the sky, and one that is lower in the sky will let you see violet. And between these two drops are others that will let you see the rest of the colors in the rainbow.

But why is the rainbow bow shaped? It’s geometry. All the water drops along this arc shape will make the angle between the sun’s rays and your eyes that allows you to see red. And these will let you see violet.

In fact, the rainbow is circular. We don’t see a full circle because the earth gets in the way, but on rare occasions, pilots have reported seeing the whole circle.

**Instructor**
Well, that kind of messes up the idea of the pot of gold at the end of the rainbow, doesn’t it? Oh well.
There are lots of misconceptions when it comes to color. For example, there are lots of ways to see red, from red laser light to white light shining through a red filter, to white light reflecting off a red object.
Let’s start with some notes.

**(text on screen)**

**VO**
The color of an object depends on the color of light that reaches our eyes.

The chemicals that make up objects absorb certain frequencies of light, and reflect or transmit the rest.

Opaque objects reflect the unabsorbed light to our eyes, while transparent objects transmit it. And it is these colors that we see.

A green leaf looks green to us because it reflects a green portion of the visible spectrum toward our eyes.

If no frequencies of light are absorbed, then all colors are reflected, and we see white.
And if all colors are absorbed, we see black.

**Instructor**
When we see the red light shining through this filter or reflected from this scarf, we’re not seeing just one wavelength, like this monochromatic laser light. Instead, we’re seeing many wavelengths, maybe as much as one third of the visible spectrum. Our minds and eyes can’t distinguish between this red or this one. So that gives us an excuse to simplify the visible spectrum. Watch this.

**(visible spectrum on screen)**

**VO**
Remember that the visible spectrum is a range of frequencies, from red to violet. Most people list the colors of the spectrum as red, orange, yellow, green, blue, indigo, and violet, or Roy G. Biv. But we can simplify the spectrum even more by dividing it into three regions. This third of the spectrum looks red to us, this one looks green, and this one looks predominantly blue.

These are called the primary colors. Since each primary color is a combination of one third of the frequencies of the spectrum, primary colors are said to be polychromatic.

RGB is easy to remember. It’s Roy G. Biv’s initials.

Instructor

Now, colors are beams of light, not paints or dyes. So when you think of a red color, think of red light coming out of a red spotlight, or red light reflecting off this scarf and reaching your eyes. When you think color, think LIGHTS, not objects. Got it? Let’s me show you what I mean.

I’ve attached primary red, green and blue filters to three projectors. Each filter will allow only that one third of the spectrum to shine through it. Now, we’ll turn out the lights and shine the three primary COLORS OF LIGHT onto different spots on the screen.

You can see that primary red is a mixture of red and orange. Primary green has both yellow and green in it, and primary blue is a combination of blue, indigo, and violet.

Now watch as I shine all three colors, or beams of light, onto the same spot. These are inexpensive filters, so the colors are not complete, but you can see that primary red plus green plus blue makes white.

Next, let’s see what we get when only two primary colors are combined. We’ll start with red and blue. The color produced is called magenta.

Primary red plus primary blue lights equals magenta

Now, we’ll combine red and green lights. Red plus green primary colors makes yellow.

Finally, we’ll combine green and blue. The result is a color called cyan. Primary green plus primary blue equals cyan.

(drawing of colors on screen)

VO

The primary colors also are called additive primaries because they add up to white.

Yellow, magenta, and cyan are called secondary colors. You should know these colors and the two primaries that make them. This triangle might help. Put the three primaries at the corners. Then fill in the secondary colors on the sides of the triangle.

Now if you shine primary red and cyan on the same spot, you’ll see white. Because cyan is blue and green, adding red produces the entire spectrum. So red and cyan are called complementary colors. A primary color plus its complement make white. What is the complement of green? Tell your teacher.

Magenta is the complement of green, and yellow is the complement of blue.
Adding colors produces more and more light. One excellent example of this is a color TV. If you use a magnifying glass and look very closely at the screen, you’ll see hundreds of groups of three pixels, which glow red, green, or blue. When all three light up, we see white, when red and green light up, we see yellow, and so on. And spotlights in a theatre are red, green, and blue. That’s all you need.

Now, what you need is some practice on adding colors.

(text on screen)
Try these questions, which your teacher will give you. Go over the answers in class before you come back. Then we’ll talk about pigments and subtracting light.

Local Teachers, turn off the tape and give students problem set number one from the facilitator’s guide.

(Pause Tape Now graphic)

Color TV’s use red green and blue pixels to create complete color scenes. But color printers use magenta, yellow, and cyan inks to produce the colorful pictures in magazines and books. What’s the difference? It’s the difference between colors of light and pigments, which are the chemicals in inks, dyes, paint and so on.

The color pixels in TV screens are like separate spotlights of primary red, green, and blue light. They add to make lighter secondary colors or even white.

But inks and dyes are chemicals called pigments. They absorb certain frequencies of light, allowing opaque materials to reflect the rest or transparent materials to transmit the rest. So they subtract colors. Better get some notes on pigments.

(text on screen)
VO
Pigments are chemicals in inks, dyes, and other colored materials that absorb certain frequencies of light, reflecting or transmitting the others.

The primary pigments are magenta, cyan, and yellow.

These are called subtractive primaries since they absorb or subtract colors from white light, letting us see what is left.

Each primary pigment absorbs a single primary color and reflects the other two, which is the color we see.
Let’s look more closely at the three primary pigments. Remember that these are not beams of light, but chemicals in materials such as paints and crayons. When your kindergarten teacher told you that the primary crayon colors were red, blue, and yellow, he or she should have said magenta, which looks like red, cyan, which looks blue, and yellow.

Magenta absorbs the green part of the spectrum, leaving red and blue to reach your eyes. Of course, you put the two together and see magenta.

Tell your teacher what color of light cyan pigments absorb.

Cyan absorbs yellow, which leaves blue and green for our eyes.

And yellow pigments absorb what?

Yellow pigments absorb blue, leaving red and green, which combine to make yellow.

So a pigment absorbs its complement.

There are red, green, and blue pigments, as well. And they, too, absorb their complements. So green absorbs magenta, or red and blue, letting you see only…. green. Get the idea?

We can show you how pigments combine by using these transparencies. Placing one on top of the other on a piece of white paper is like mixing inks or dyes together. And you can see that instead of making us see more light, as we do when colors of light are mixed, we see less and less light, eventually getting black. Remember that mixing pigments is a subtractive process.

Three-color printing processes use magenta, cyan, and yellow inks in separate dye baths. The final result is this, a full color picture.

Now, you’re going to be asked questions such as “What color do we see when we shine red light on a mixture of cyan and magenta pigments?” That sounds hard, doesn’t it? But we’re going to show you a method that makes it easy and fun. I promise.

Let’s start with this question that is so obvious you’ll think it’s silly. What color do we see when white light shines on a red pigment, like a tomato? I know you’re thinking, “Red, of course.” But remember that I’m showing you a method, so be patient.

When you solve a color problem, you’ll use the color block method. You’ll use three-color blocks to represent the three primary colors of the spectrum. Above the blocks, you’ll label R, G and B. You don’t have to use any pictures of spotlights, but imagine the three primary colors of light that make up white light shining down on the pigment. You’ll write the pigment here.

Now comes the most important step. Think about what color of light the pigment absorbs, and shade in that color block or blocks. You can use a color triangle to see that a red pigment absorbs its complement, cyan light. Or you can just use logic, knowing that only red will be reflected, so green and blue must be absorbed. Either way, we shade in the blue and green blocks.
Now, turn on the lights and see what happens when they shine down. Since we’re using white light, that’s all three. When red light shines down, it’s reflected back up to your eye. When green light shines down, the shading tells you that it is absorbed. I’ll show it like this. What happens to the blue light? It’s absorbed, too. So only red reaches your eye.

**Instructor**

Now let’s go one step farther. The color of an object also depends on the color of light shining on it. What will you see when red light shines on a red object, like our tomato? Or what will you see if you shine only green light on the same tomato?

*color blocks on screen*

**VO**

This time, you do the same as before, shading in the green and blue blocks. Now, let’s deal with the colors shining down. This time, we’ll turn off the green and blue lights and only shine the red light. It is reflected, so the tomato still looks red.

But what about turning on only green light. The green light comes down and is absorbed. So nothing gets to your eyes. The absence of color is black, so a red tomato will look black in green light.

**Instructor**

Let’s check our results. We could turn out all the studio lights and shine only red or green light on this tomato. But the crew always plays tricks on me in the dark. So I’ll keep the lights on and place this red filter directly over the picture so that it will let only red light hit the pigments in the paper. You can see that the tomato looks red.

Now, let’s use the green filter. And sure enough, the tomato looks black. So far, so good. Now it gets harder. Let’s try example two.

*color blocks on screen*

**VO**

We’re asked what we see when white light shines on a mixture of blue and yellow pigments.

This time, we’ll use two sets of color blocks since we have two pigments mixed together. The blue pigment reflects only blue, so we’ll shade the red and green blocks. Blue absorbs its complement, yellow, which is red and green.

Next is the yellow pigment. Yellow absorbs its complement, which is blue. So let’s shade in the blue. Now let’s turn on all the lights, since we’re using white light. Now to be reflected the light has to get through both layers of pigments. If either or both layers absorb it, it’s gone. So look what happens. Red is absorbed. Green is absorbed, and so is blue. We see no colors, and that’s black.

Yellow plus blue pigments make black.

**Instructor**

We can use our transparencies to check our results again. We can stack blue and yellow transparencies to show the mixing of the two pigments. And sure enough, we get black.

But what about blue plus yellow makes green? People who tell you that are well meaning, but they’re not talking about primary blue. Maybe they mean cyan. Let’s try that problem together before you
try some on your own.

*(color blocks on screen)*

**VO**

Cyan absorbs its complement, which is red, so I’ll shade in the red. And yellow absorbs blue, so I’ll shade that in. Now we shine all three colors down making white light.

The red is absorbed, and the blue is absorbed, but the green is reflected. So cyan and yellow pigments make green.

**Instructor**

Check it out. Cyan plus yellow makes green.

I think you’re ready to try some color problems on your own now. Your teacher will give you these and time to solve them. Then you’ll go over the answers in class.

Local Teachers, turn off the tape and give students problem set number two from the facilitator's guide.

*(Pause Tape Now graphic)*

**Instructor**

Now, it’s important to remember that the colors we’ve been working with are ideal or pure. You might mix real pigments and get different results because the pigments don’t absorb as much of the spectrum as ours do. And of course, paints have a lot of white mixed in, so you won’t get black paint by mixing others.

So we’ve discussed pigments and lights. Does any of this tell us why the sky is blue? You know that light coming from the sun is white, a combination of all frequencies of visible light. On its way to the earth, the sunlight passes through our atmosphere where some of the light is SCATTERED in all directions. Watch this to learn some more about scattering. And fill in the blanks in your notes.

*(diagram on screen)*

**VO**

When the light waves hit molecules in the air, the molecules absorb certain frequencies, depending on the size of the molecules. This energy makes the molecules begin to vibrate at the same frequency, and they give off the same color of light in all directions. This is called SCATTERING.

The smaller the molecule, the higher the frequency of visible light that is scattered. In our atmosphere, small nitrogen and oxygen molecules are most abundant, and these scatter blue and violet light, which is the primary blue part of the spectrum, all over the sky. No matter what direction you look, you’ll see this blue light.

Now, when you look up at the sun, you’ll see the rest of the light that is still coming directly at you. Notice that I’ve removed the blue and violet, since that has been scattered. So we see white minus primary blue, which is red and green, or yellow.

*(physics challenge on screen)*

**VO**

Here’s a physics challenge for you. Explain to your teacher why the sky on the moon is always black. And tell your teacher what color the sun would appear from the moon.
Instructor
Did you know that the moon has no atmosphere? So there can be no scattering of light to color the sky. And that means the sun will look white to astronauts standing on the moon.

Now, here’s another question. Why does the sun look redder at sunset? And what causes the beautiful colors of the sky during some evenings? Watch and learn.

(diagram on screen)

VO
In the evening, the sun is lower in the sky. This means that sunlight has to travel through more of our atmosphere to get to us. And you can see that it bends, too. We’ll talk about this refraction in another program. But the result is that more scattering occurs, and some of the larger molecules get a chance to scatter more light in the green portion of the spectrum. That makes the sky more cyan in color, and the sun looks white minus this part of the spectrum, which is more orange or red. The more large molecules in the atmosphere, due to pollution, the more light is scattered and the redder the sun will look.

Larger particles, such as water drops or dust, are too big to scatter light. They reflect it instead. This is the reason for the colors in the sky at sunset.

Instructor
So some of our prettier sunsets are caused by air pollution. Doesn’t that give you a warm, fuzzy feeling? And in the years to come, won’t your children be impressed to hear mom or dad explain why the sky is blue.

That’s it for our unit on the nature of light. Next unit we’ll study optics. I might even explain why I have to wear these glasses. See you then.

Upbeat music plays as film fades out.