Shedding Light on Colour

Teachers' Notes

Program Summary

Join presenter Spiro Liacos as he looks into all things colour! What is colour? How can objects have different colours when the light shining on them is white? How is coloured light produced? What happens when we mix coloured light? How does a TV produce a picture? Why is, for example, green paint produced when you mix yellow and blue paint? How do we produce the colours in photos and magazines? What is light? How do our eyes and brain see colour? What is colour blindness? Can animals see colours like we do?

Timing Information

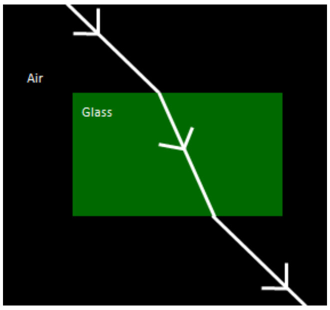
00:00	Part A: Coloured Light
09:21	Part B: Mixing Coloured Light
16:19	Part C: Mixing Paints and Inks
21:25	Part D: Coloured Light and Vision

Preview the video at www.liacoseducationalmedia.com

Part A: Coloured Light

Colour is all around us. Nearly everything seems to be coloured in one way or another. But what is colour? How do we get colours when sunlight is white. And incandescent light (the light produced by objects that are really really hot) is white. And our fluorescent lights are white.

It turns out that white light is actually a mixture of lots of different colours, the colours that make up a rainbow: Red, Orange, Yellow, Green, Blue, Indigo and Violet. The name “ROY G BIV” is a useful mnemonic. This spread of colours is called a spectrum.

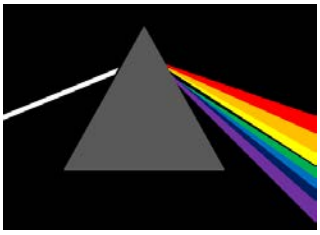


When all the colours are mixed together, we perceive the light to be white.

We can separate white light into its component colours using a prism.

When light passes from one transparent substance to another at an angle, it refracts. However, the component colours of white light all refract by a slightly different amount. The red light refracts the least and the violet light refracts the most, with all the other colours spread out in between.

So, knowing that white light is made up of lots of different colours, why does a blue object look blue? And why does a red object look red?



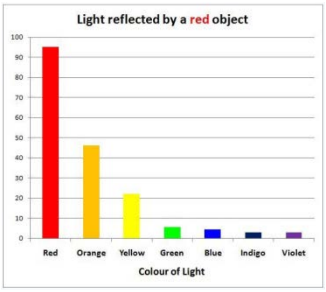
A blue object looks blue because when white light strikes it, the chemicals that make it up only reflect the blue light, but very little of the other colours. In a similar way, a red object is red because the chemicals in it reflect red light very well, but the other colours are absorbed.

A common statement students make is that a red object is red because it’s red! The video shows them that light has to reflect from something for us to see it, and the colours that reflect from the chemicals that make it up are what “give” it its colour.

When there’s no light, everything looks black; remember, there’s no such thing as dark light; black or darkness is just an absence of light. Turn the light on and white light, made up of all the colours, shines onto the object. If only red light reflects, we see that the object is red.

What about white objects? White objects reflect all the colours equally well.

And black objects? Black objects reflect very little light, but instead absorb the light’s energy. As a result, black objects tend to get hotter than white objects when left out in the sun.

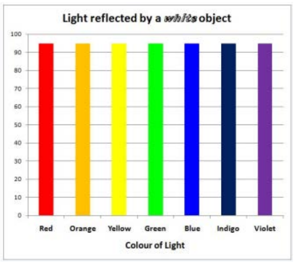


In the sun, a white T-shirt, reflecting most of the light that hits it, does not get as hot as a black T-shirt, which absorbs the light and does not reflect as much.

In reality, it’s a little more complicated. A red object reflects a lot of red light, but also reflects a little orange and yellow, since these two colours are next to it on the spectrum. A graph of the amount of light being reflected looks something like the graph at right.

Now there are lots of different shades of red, so the graph of reflected light would vary, but all red objects would reflect more red light than any other colour.

A blue object reflects blue light, but also smaller amounts of the other colours.



Yellow is a little different. Yellow objects reflect lots of red, orange, yellow and green, and we see this combination as yellow. Yellow chemicals are bright because they reflect lots of light.

The Light reflection graph for a white object looks like this; all the component colours of white light reflect, while for a black object, very little light reflects.

Filters are similar. A red filter reflects mostly red light, but also allows red light to pass through it. The other colours of light are absorbed. In a similar way, blue filters allow blue light to pass through, while green filters allow green light through.

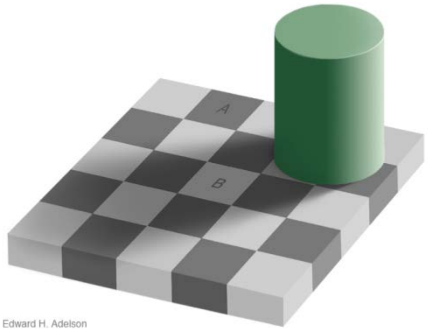
The type of light shining onto an object, and the colours that surround it, actually change the way that we see objects. In direct sunlight, coloured paper can easily be seen for what it is, say red, green, blue, orange and white. However, what happens if you try to shine red light onto green paper. As we've discovered, green paper only reflects green light. Red light is absorbed by the green paper, and no light reflects, so what we would normally call green, appears black.

In a similar way, green light shining onto red paper makes the paper look black because no light is reflecting.

This effect is not a psychological or physiological effect. If a piece of paper doesn't reflect light, it will appear black.

However, our psychological and physiological perception of an object's colour can change enormously depending on the colours that surround the object. Using a projector, we can shine images onto a white screen. If we draw a black rectangle in a Word document, the rectangle can't really be black because, in fact, projectors don't project black; they can only project light. The black square is actually where the projector isn't projecting any light at all, which means it must be the same colour that the screen is when the projector isn't even on, that is white. In fact, the screen and the rectangle are grey, but they look black because the surrounding whiteness is so much brighter.

The checkerboard illusion, created by Edward Adelson, shows us much the same thing. Squares A and B appear to be different shades of grey, but in fact, they aren't.



Part B: Mixing Coloured Light

Our perception of colour is also influenced by the mixture of colours that enter our eyes. As we've already seen, when all the colours of light enter our eyes, we see white. But different combinations of coloured light produce what appear to us to be different colours. The three primary colours of light are red, green, and blue, and we can use these three colours to produce any colour we want.

If we used a red and green filter to shine red and green light onto a screen together, the reflected light enters our eyes at the same time and we perceive the colour to be yellow. If the red light is made slightly brighter than the green, we see orange. Mixing green and blue makes us see cyan. And mixing blue and red makes us see magenta. Mixing all three produces white light.

But how often do we observe the mixing of colours? Well, as a matter of fact, pretty much every day when we watch TV. An LCD TV screen is made up of thousands of tiny liquid crystal sub-pixels. In front of each sub-pixel is either a red, or a green, or a blue filter. Behind the liquid crystal array is a white-light source, usually rows of white LEDs.

Each liquid crystal sub-pixel is connected to the electronic circuitry of the TV and its transparency can be controlled. The electronic signal can make each liquid crystal unit completely transparent, completely opaque (that is non see-through), or somewhere in between.

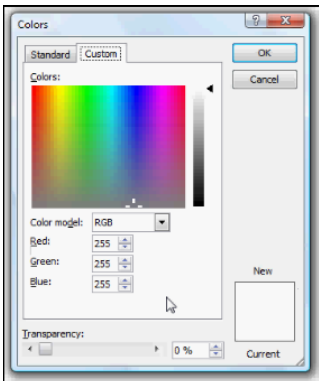
By controlling which sub-pixels are on and off and the extent to which they allow light through, a picture is built up on the screen, a picture that is actually made up of thousands of tiny red, or green or blue lines.

Using a microscope, we can zoom in on an LCD monitor and see the red, green and blue lines that make up the screen.

In the white rectangle, all three primary colours of light are visible: red, green and blue. In a red rectangle, only the red lines are visible and the green and blue sub-pixels are switched off.

To achieve dark red, the liquid crystals allow only some of the back light through; same colour light but not as bright.

To achieve green, the green lines shine while the others remain dark, and likewise for blue.
To produce yellow, the red and green lines shine while the blue lines switch off.
Plasma TVs and CRTs, or Cathode-Ray Tubes produce their light in a different way, but all essentially form a picture from tiny little red, green and blue dots. However, cathode-ray tubes emit small amounts of X-rays, so no-one should use a microscope to view the screen up close.
The large screens used at concerts and sporting arenas are also made up of tiny red, green and blue lights.
We can control the colour on a computer screen using the computer's colour-control software, which allows us to control the colours of the red, green and blue subpixels on a scale from 0 to 255.



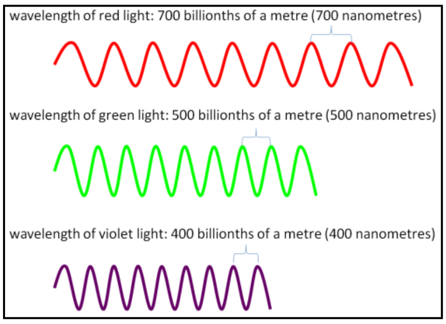
Color model: RGB
Red: 255
Green: 255
Blue: 255
Transparency: 0 %

Part C: Mixing Paints and Inks

The three traditional primary colours of pigments are red, yellow and blue. (Technically, a pigment is a chemical that is coloured, while the "paint" is the smooth, creamy stuff that we add pigments to so as to give the paint its colour.) Mixing red and yellow produces orange, mixing yellow and blue produces green and mixing red and blue makes purple.
It's easy to explain this if we go back to the way that coloured objects reflect light. As we saw, red objects reflect mostly red light but also reflect a significant amount of orange, but they do not reflect much of the other colours. Yellow objects reflect mostly yellow light but also significant amounts of red, orange and green light, since these colours are next to it on the spectrum, but only small amounts of the other colours. When red and yellow paint form a mixture, the red pigment takes away most of yellow, green, blue, indigo and violet light and the yellow pigment takes away a lot of the red, and most of the blue, indigo and violet, so the winner—the colour that is absorbed the least—is orange. So that's what we see.
Once again, by mixing varying amounts of the primary colours, you can produce a huge range of colours. However, red, yellow and blue don't produce as many colours as we'd like, so the four so-called process colours of cyan, magenta, yellow and black are used in the printing of newspapers and magazines. These colours produce a greater range of colours when mixed.

Part D: Coloured Light and Vision

So why light does come in different colours? And how do our eyes and brain work to perceive those colours? To answer these questions, we need to explain something that, at first, seems totally unrelated. Scientists discovered some 200 years ago that moving a magnet next to a coil of wire produces electricity, and electricity moving in a coil of wire produces magnetism.
It was then discovered that fast-moving electrons in for example a spark can produce an electric-field wave that travels out through space, similar to the way a wave can move along a slinky. But the electric-field wave then produces a magnetic-field wave, which then produces an electric-field wave and so on. These waves move out at the speed of light: 300,000 km/second, or about 8 times around the equator of the earth every second. We now know that light is made of these alternating waves of electrical and magnetic fields.
Students have real difficulty understanding this concept. A magnet is made of metal; it is something you can touch, they say! But in fact, a magnetic field can exist on its own, without an actual metallic magnet. Light is a very-fast-moving wave of magnetic and electrical energy.
We can distinguish between the different waves using what we call the wavelength of the wave. The wavelength of the wave is a measure of the distance between each crest. The wavelength of red light is only about 700 billionths of a metre. Green light has a



wavelength of about 500 billionths of a metre, while violet light has a wavelength of about 400 billionths of a metre.

In fact it’s often more useful to talk about light’s wavelength than it is to talk about its colour, because the seven colours of the rainbow actually blend into each other. There are a range of reds, which blend into reddy oranges, which blend into a range of oranges and so on.

So how do we see colour? The eye’s lens and cornea form an image on the retina at the back of our eyes, much like a lens forms an image on a screen.

At the back of our eyeballs, on the retina, we have two types of light-sensitive nerves: cones and rods. These cells are triggered when light strikes them, and they send off a signal to the brain.

The 5 million or so cone cells allow us to see colour and come in three varieties: some are more sensitive to long wavelength light at the red end of the spectrum, some to medium wavelength light in the middle of the spectrum, basically green light, and some to shorter-wavelength light at the blue end of the spectrum.

When red light enters our eyes, the red-sensitive cones respond by firing off a signal to the brain and we know that the object is red. Similarly, blue light triggers the blue-sensitive cones. Different blends of colours stimulate each of the different cone cells by a different amount and our brains interpret the resultant colour. The cone cells require fairly bright conditions to be stimulated, and that’s why we can only see colours clearly when there's plenty of light.

Colour-blind people though, have a reduced capacity to distinguish colours, but very few people see only in black and white. Most people who are colour blind have red-green colour blindness; they have trouble seeing reds and greens but see everything in blues and yellows. However there are different types of colour blindness and various tests have been developed to diagnose it. The Ishihara tests are probably the most well known.

The 90 million rod cells in our eyes are far more sensitive than the cone cells but they don’t provide information to the brain about the colour of light; they just send off a signal telling the brain that some light has hit them. In dark conditions, when the light isn’t strong enough to trigger the colour-sensitive cone cells, the rod cells allow us to see. However, because they don’t provide information about colour, everything looks grey.

In a sense, we’re all colour blind in very dim light.

Some people say that animals are colour blind, but, in fact, most animals, including birds, insects, primates and marsupials, and reptiles can see colours very well. Animals rely on colour to find food or a mate. For example, peahens tend to choose the brightest, most colourful peacocks to mate with. And bees use colour and smell to find the right type of flowers.

However, many mammals like dogs, cats and rabbits, can’t distinguish colour very well even in bright light because they only have two types of cone cells and they have a lot fewer of them than humans.

And dolphins, seals, whales and other marine mammals have only one type of cone cell, so it’s believed that they can’t distinguish between any colours at all. However, they don’t necessarily see only in black and white; we don’t really know how they see the world.

Dolphins can be taught lots of tricks, but no-one has ever been able to teach ol’ Flipper to go fetch the red ball!

Activities before the program.

1. **Write down as many things as you can think of that emit (give off) light (that is, that are "luminous").**

Answers could include: the sun, stars, light globes (including domestic lights, headlights in cars, torches and more), fluorescent tubes (the compact ones and the long ones), fire (in a fireplace, a gas lantern and more), lasers, fireflies, LEDs, TVs (plasmas, LCDs and cathode-ray tubes), a piece of hot metal that has just been taken out of the fire, molten metal, lava, halogen lights, Glo-sticks, phosphorescent decorations that glow in the dark…
At the end of the individual brainstorm, go around the room and get the students to call out what they have written down. Let every student tick their responses if someone else has thought of it as well. The winner is the student who has thought of a light source that no-one else has thought of.

2. **Write down as many things that you can think of that are transparent.**

Answers could include glass, air, a vacuum, space, our cornea, the fluids inside our eyeballs, clear plastic (of which there are many types), cellophane (which is a clear plastic that has a name), water.
Turn the activity into a game as described above.

3. **List five devices or things that are specifically designed to produce coloured light.**

Answers could include TVs (LCDs, plasmas, and cathode-ray tubes), neon lights, Brake lights, indicators, glo-sticks, lasers, coloured light globes, glo-sticks, glow-in-the-dark toys, traffic lights, luminous speed-limit signs and traffic warning signs, LEDs, advertising billboards, advertising signage, large screens at sporting grounds.

Notwithstanding this extensive list, most of the light produced everyday comes from the sun or from fluorescent tubes and light globes.

4. **What colour is sunlight and the lights used in our homes and schools?**

White!

5. **If only white light shines onto a red pencil and a blue pencil, why does one appear red while the other one appears blue?**

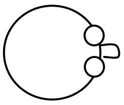
Allow the students to come up with some theories and then show the **"Shedding Light on Colour"** video.

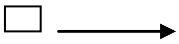
As they will soon learn, white light is made up of red, orange, yellow, green, blue, indigo, and violet light. A red pencil reflects the red-coloured light and absorbs the other component colours of white light, while the blue pencil reflects the blue-coloured light and absorbs the other component colours of white light.

Activities to try after the program.

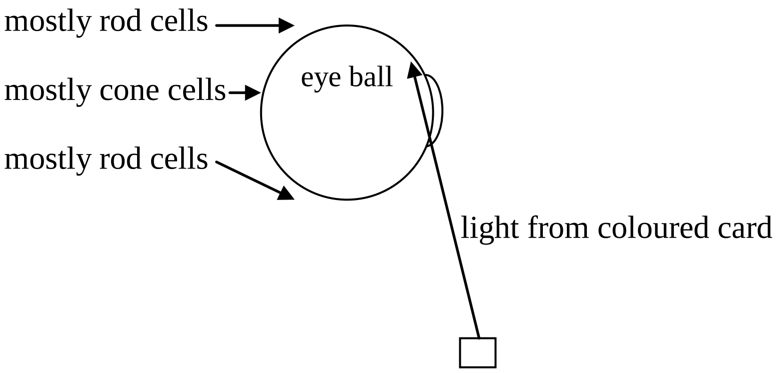
1. **Determining the location of rod cells and cone cells.**

Have a student volunteer face the class and look directly at a point at the back of the room. Wave a coloured card at a point where it would be impossible to see, and slowly move it forward. Ask the student to tell you the card's colour.



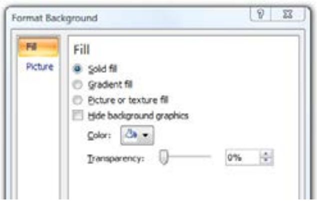
Coloured card waving 

At some point, they will see the card waving, but will not be able to tell you its colour. This is because the light is travelling into the eye at an extreme angle and there are very few cone cells at the side of the retina; most of our cone cells are concentrated directly at the back of the retina.



2. **Shining coloured light onto coloured cards.**

Use Powerpoint to create 7 blank slides, each with a different coloured background: white, red, green, blue, cyan, magenta, and yellow. (Click Format Background and then the "Color" drop-down button.)
Using a projector, project the coloured light onto a white screen in a darkened room. Stick some coloured cards onto the screen and ask students to try to work out which card is which. Many of the cards will appear much darker than they would normally appear in white light, and some will appear to change colour completely.
At first, you can make it a guessing game by not revealing what colour the cards are (in white light), and then you can get students to fill in a table like the one below.

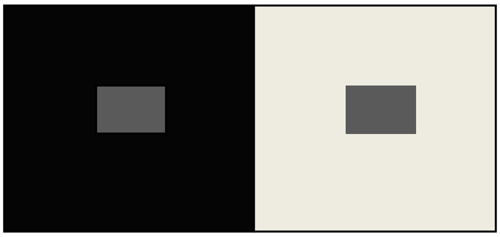


● Solid fill
○ Gradient fill
○ Picture or texture fill
☐ Hide background graphics
Color:
Transparency: 0%

	Apparent colour of cards when different colours of light shine on them					
Light Colour	"red" paper	"orange" paper	"yellow" paper	"green" paper	"blue" paper	"violet" paper
white						
red						
green						
blue						
cyan						
magenta						
yellow						

3. **Optical illusions.**

Ask the students to create an optical illusion similar to the one shown in the video. The two grey rectangles below (which are inside the squares) are the same colour. Is this effect easy to re-create? Does it work with shades of, say, blue, green, or red?



4. Colour Blindness.

As described in the video, red-green colour blindness is the most common form of colour blindness. People with red-green colour blindness see things in shades of blue and yellow. Seeing only in black and white is very very rare. Let’s assume for a moment that you were born with an inability to recognise any colours at all, that is, you saw everything in “black and white” (which of course includes grey). Write down five problems you might experience as you go about your day-to-day activities. You may want to show students a 5-minute clip from a B&W movie.

Answers could include: knowing whether fruit was ripe; food had cooked or browned; recognising traffic lights, particularly at night; colour co-ordinating your clothes; noticing warning labels and signs; recognising when you’re getting burned in the sun; colouring in; distinguishing between the red wire and the blue wire when you’re about to diffuse the bomb…