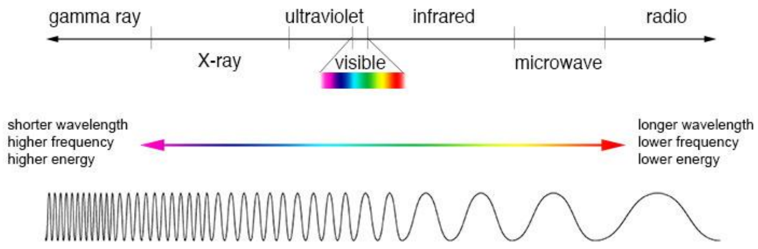
Colour

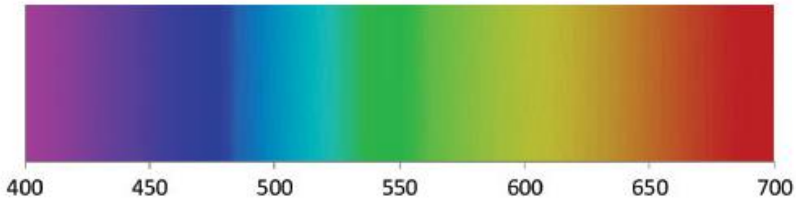
Steve Wells

The Colour Spectrum

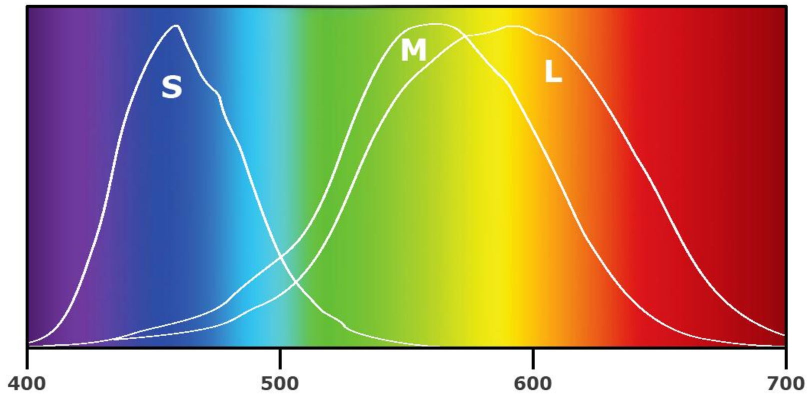
The light we see is just part of the electromagnetic spectrum which in its entirety includes everything from gamma rays and x-rays to radio waves.



The Electromagnetic Spectrum



The Visible Spectrum



The Response of the Human Eye

The part of the spectrum to which our eyes are sensitive is just a very small part in the middle. We see it as a range from red to deep blue but this is just how our brains see it. There is nothing intrinsically coloured about light.

In order to understand where colour comes from we need to take a quick look at how the human eye captures colour information.

In the centre of the retina are cells called "cones" (because that's what they are shaped like!) There are three types of cone, each sensitive to a different part of the visible spectrum. Technically they are called S, M and L for short, medium and long wavelengths. We, on the other had think of them as Blue, Green and Red (even though the Long cones are actually more sensitive to yellow than to red.) These cones and their sensitivities to red, green and blue is where we get the RGB colour spaces we use in photography.

If you look inside a JPG file, for each pixel there are three numbers which give to the amounts of red green and blue which have to be mixed together to create the required colour. This raises an important question. Exactly which red green and blue are we talking about?

If you imaging going on a country walk in the spring, how many greens can you see? The grass is not the same as leaves on a tree. Sunlit grass is not the same as grass in the shade. There are hundreds of greens. The same goes for red and blue. So, to get accurate colour photographs we need a definition of the particular colours we are talking about.

More of this later.

Colours in Practice

Primary and Secondary Colours

If you ask a painter what the primary colours are she will probably say red, blue and yellow... but, so far we have been talking about red green and blue! Why the difference? Well primary colours are the colours which can be combined to get other colours. It all depends on how you do the combining.

In photography we effectively start with nothing (black) and add the colours we need. This is an additive process and the primaries are red, green and blue.

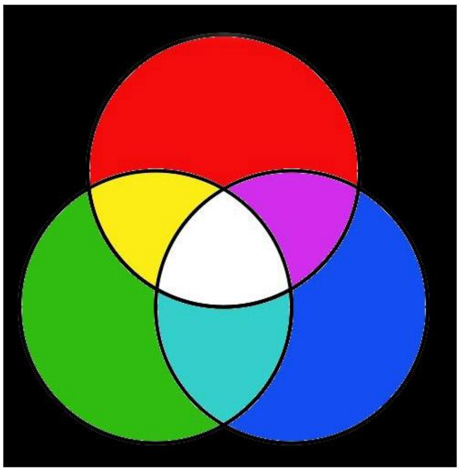
A painter, on the other hand shines white light on to a painting to see it. She starts with everything (white) and the pigments remove the colours which are not required. In this subtractive process the primaries turn out to be red, yellow and blue.

There has to be something more linking these different sets of primary colours. Here we have to think about secondary colours. A secondary colour is what is left if you start with everything (white) and remove a primary colour:

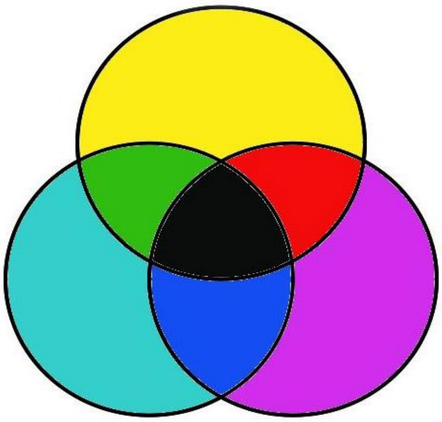
- Remove red (primary) from white and you are left with cyan (secondary);
- Remove green (primary) from white and you are left with magenta (secondary);
- Remove blue (primary) from white and you are left with yellow (secondary);

So, what are these new colours magenta, yellow and blue? Well, magenta is close to red, and cyan is a kind of blue. So these secondary colours in photography turn out to be the same as the primary colours for the painter. The reverse is also true.

So, we have two ways to combine colours and a set of primary colours for each. The primary colours in one system turn out to be the secondary colours in the other.



ADDITIVE: Start with BLACK and add colours. Pairs of colours add to produce secondary colours. When you have added everything you get WHITE.



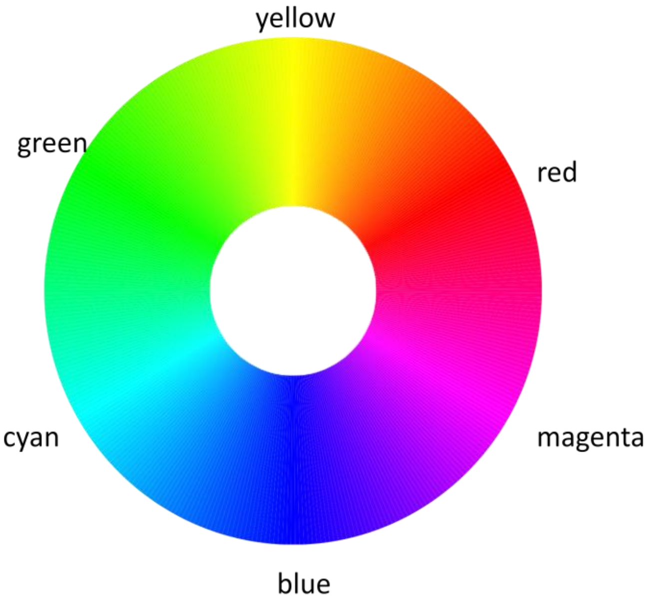
SUBTRACTIVE: Start with WHITE and subtract colours. Pairs of colours subtract to produce secondary colours. When you have subtracted everything you get BLACK.

The Colour Wheel

Here is another way to represent the colours: in a circle

In this diagram the primaries are arranged round a circle with the corresponding secondary colours opposite them.

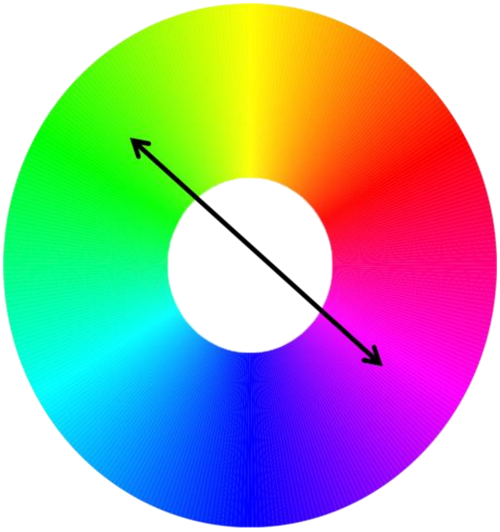
So, for example, the secondary of red is cyan. Red and cyan appear on opposite sides of the circle.



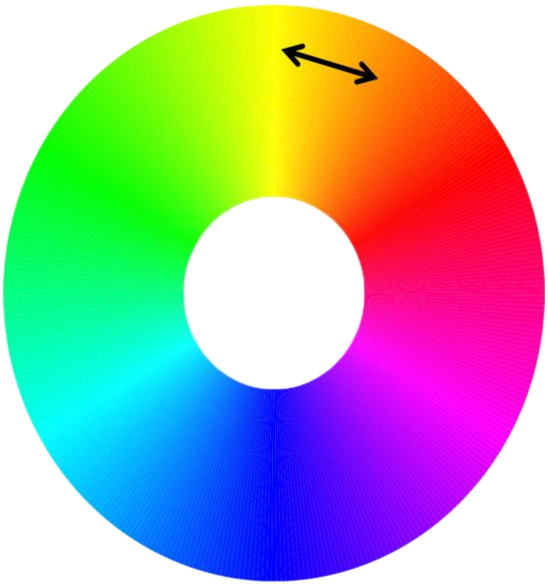
Colour Wheel

The colour wheel can be used to identify colours which are in harmony or in contrast. Colours close to each other are in harmony. Those which are far apart are in contrast.

Here are a couple of examples

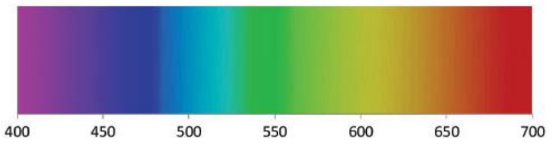
Green and Magenta: Opposite sides of the wheel tend to clash

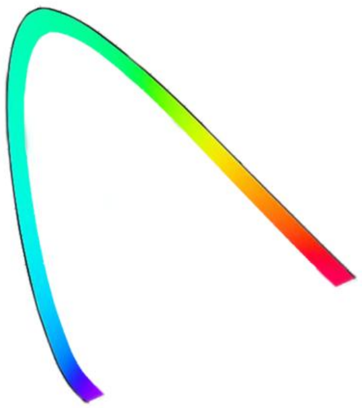
Yellow and Orange: Same side of the wheel tend to harmonise

Defining Colours

WARNING! This section has a lot of sophisticated mathematical theory supporting it. So I will use pictures but there will be a number of unsupported statements. If you want to see the explanation, go to the maths!



The Visible Spectrum



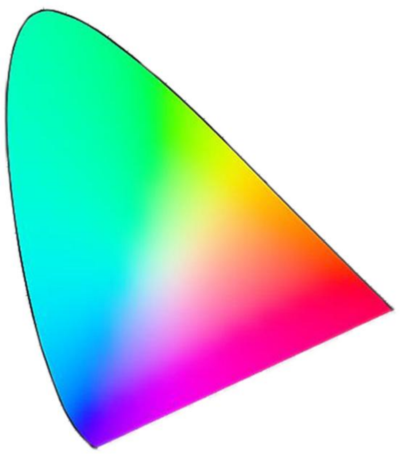
Horseshoe made by bending the Visible Spectrum

Earlier we saw the visible spectrum as a line running from blue to red. Now, I want you to imagine this line as a kind of horseshoe

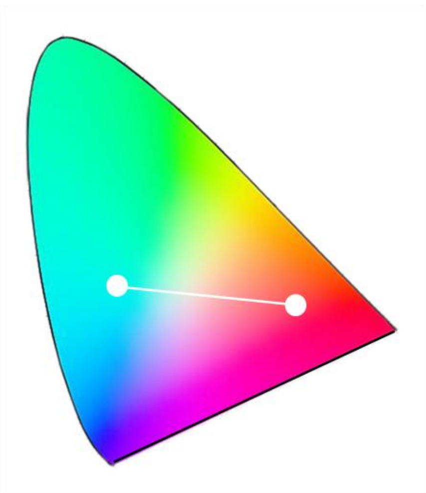
The colours are the same – follow them round from blue to red.

The theory supporting the shape of this horseshoe shows that the space inside the horseshoe can be filled in with other colours. In theory, all the colours that human eye can see are represented. This diagram is known as the CIE Colour Diagram.

The way there colours are filled in has a special property. If you take any two colours, all the colours you can get by mixing these two colours (additively) are on a straight line between those two colours.

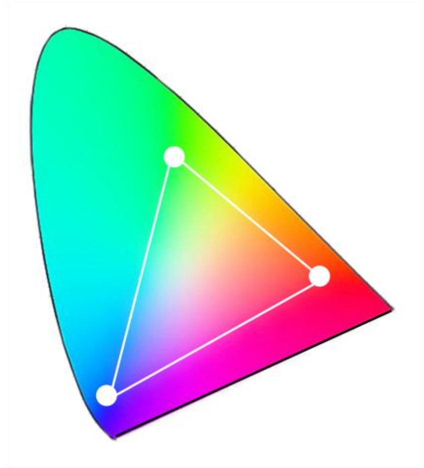


"Commission Internationale de l'Elcairage" (CIE) Colour Diagram



The colours you get by mixing two colours lie on a straight line between those colours.

You can take this a stage further. If you take three colours (a red, a green and a blue, perhaps) forming a triangle, then all the colours you can get by combining the three will appear inside the triangle.



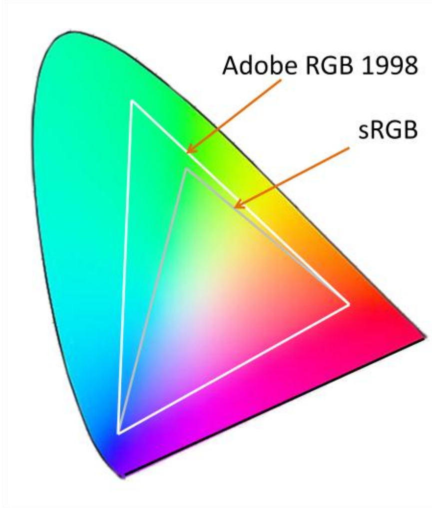
All the mixes of the three colours lie inside the triangle.

So, the CIE diagram allows colours and their combinations to be defined accurately.

Earlier we talked about a JPG file and the three numbers for each pixel which define a particular colour. We also noted that this was not enough. What was needed was a definition of those colours. Well, here is the answer.

We can take three colours accurately defined within the CIE theory and use those definitions within the JPG file.

A definition of three colours like this is called a “Colour Space”.



Colour Spaces

The colour space defines the colours used by the JPG file to mix to create the colours in our photographs.

These colour spaces have names which we have become familiar with – “sRGB” and “Adobe RGB 1998” in particular. There are many more.

Now, if you look at the CIE diagram showing the sRGB and Adobe RGB 1998, you might think that because the Adobe colour space includes more colours, then it must be better!

This is where the real world gets in the way of the theory.

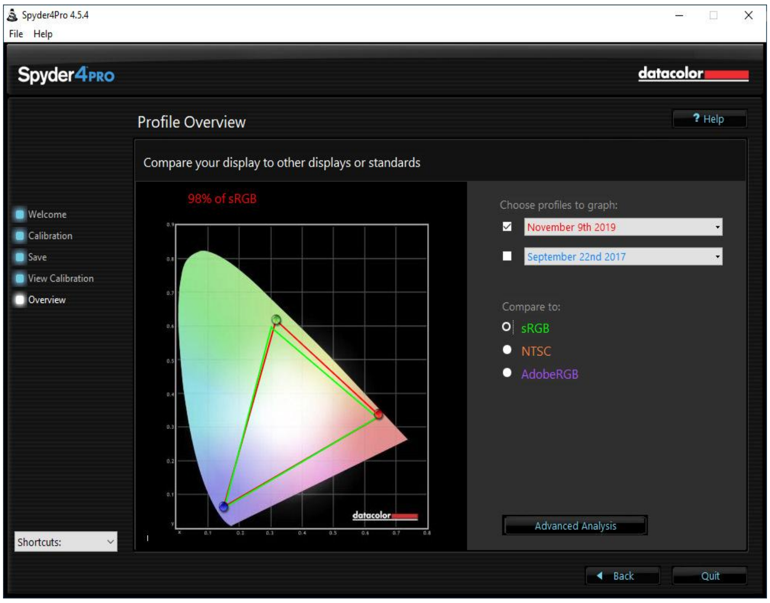
The objective of photography is not to give colour experts a forum for showing off their mathematics. The objective is to take pictures. Pictures exist in the real world. They have to be displayed on a screen, as a print or as a projected image. What is important in each case is not colour theory, but the actual colours which can be reproduced by the real hardware.

Most screens, printers and projectors come close to sRGB. You can get equipment which can display more colours – at a price.

Camera Club projectors use sRGB. The lab I go to for printing specifies that images should use sRGB.

Of course, there is another point about the real world. When you see an image which uses sRGB, have you ever noticed any colours missing? I thought not!

The next question, then, is how close real hardware comes to colour theory. We calibrate printers in order to get as close as we can. When I calibrate my monitor, at the end of the process, it comes up with a screen showing a comparison between my screen and the theory.



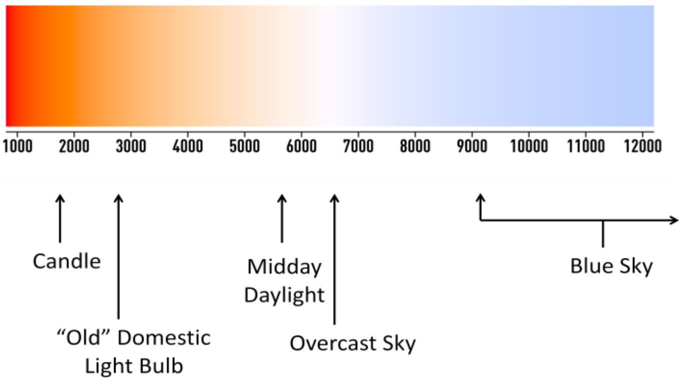
Datacolor "Spyder 4" screen showing the results of monitor calibration.

It displays the, by now familiar, CIE diagram with sRGB and my monitor for comparison. At the time I did this particular calibration, my monitor was covering about 98% of sRGB. That is actually pretty good. Cheap screens designed for call centres will often show only 70% of sRGB. This does not mean they are bad screens. It means they are designed for a different job.

Colour Temperature

Up until a few decades ago all light sources were created by heating or burning. The exceptions today are fluorescent tubes and LEDs.

When something is heated or burned, the colour of the light depends on the temperature. So, the colour can be defined by specifying the temperature.



Colour Temperature

We use colours sometimes to describe temperature – think of "red hot" and "white heat". (Emotionally we think of blue as cold and red as warm, but this is wrong: in colour temperature terms, blue is much warmer than red.)

Using the Kelvin scale, midday daylight is about 5600 K.

With excellent auto white balance available on most cameras, it is rarely necessary, these days, to worry about the colour temperature of light sources.

It is still important, however, when comparing colours of images. If you want to compare colours on a print with colours from the same file displayed on a screen you need to match the illumination. A screen is typically set a little bluer than daylight at about 6500 K. Ideally then print should be illuminated with a lamp at the same temperature. In practice, a daylight balanced lamp will do the job – standard domestic lighting will not.