Colour in Art and Science
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There is a Powerpoint presentation accompanying this talk

Tonight we're going to think about colour: what it is, where it comes from, and what it means.

Even if we know nothing about the first two—what colour is and where it comes from—we all have ideas about what it means.

[Pick some people and ask them why they like to wear what they're wearing. See if anyone is wearing yellow, and if not, ask if anyone would (and why not!)]

In China a few hundred you wouldn't have been wearing yellow either, but for a very different reason: you would be risking a death sentence. Only the Chinese emperor was allowed to wear yellow, right up to the 20^{th} century. The word for yellow and the word for emperor—*huang*—are the same in Mandarin Chinese.

The same was true of purple in ancient Rome. During the reigns of some of the Roman emperors, no one but the emperor himself could wear a purple robe. It was sometimes permissible for generals and government officials to wear little bits of purple—bands at the borders of their togas, for example—and this showed that they were someone very important. But if you wore more purple than your rank allowed, you were in serious trouble. Anyone other than the Imperial dye works who tried to make and colour cloth with a pruple dye was liable to be executed.

So if you think it is important what colours you wear now, it was once a matter of life and death. Colour was used to send out a very clear and important message about one's status in society. Why purple, though? Well, I'll tell you shortly.

Colour is a very immediate way of telling other people who we are and what we think. For example: [pic of football supporters]
We don't know anything about who these boys are, but we know right away that they support Man United. And of course, they have chosen their colours to match those of the team strip itself [pic]. On the football pitch, colour helps the players distinguish their side from their opponents.

Well, this is all part of an old tradition. [pic of foot soldiers from the Napoleonic era.] Today, soldiers tend to wear camouflage in order not to be seen, but in earlier times warfare was conducted in a very different way, with armies marching to face one another in massed ranks, and the main thing was to distinguish friend from foe. These colours might also be chosen for other reasons. The British redcoats, for instance, relied on a reputation as staunch and well disciplined fighters, which they thought would be enhanced if they looked splendid. It is also said that the red coats were good for morale because they helped to hide the blood of the wounded.

Even longer ago than this, colour use in armies was more complicated. [Heraldry pic] Knights used colour to say a lot about themselves. They wore the colours of their coats of arms, which announced their family history. But it didn't immiediately show whose side you were on! It would be like playing in a football match (a pretty lethal one) where every player is wearing a different strip. In those days of chivalry, knights at least were expected to recognize the colours and emblems of other knights. They clearly felt it was more important to tell people "I'm the Duke of Cornwall" or "I'm the Duke of Anjou" than to say "I'm fighting for the English" or the French.

The ancient Britons had a much simpler uniform when they fought the Roman invaders around the time of Julius Caesar: they painted it straight onto their bodies. [pic] It was a blue dye called woad, and it made them look fearsome. Julius Caesar said:
"All Britons dye themselves with woad which makes them blue, in order that in battle their appearance is more terrible."

Colour wasn't just important in military life, but also in civilian and religious life. [Pic of Thomas More & family, early 16th C, showing red- and black-robed figures]. Point these out, and ask: Why red? Why black? We'll see the answer shortly.

And look at this painting. It is by the Italian artist Titian, who lived in the sixteenth century and painted this over the course of almost ten years. It shows the Virgin Mary and various saints, as well as some of the members of the rich family, the Pesaros, who paid Titian to paint it. It's not that the Pesaros simply wanted a nice picture: wealthy people in those days often paid a painter to paint a religious scene to decorate a church or an altar, which would show how devoutly religious they were—it was like giving an offering to God. But you see that they were often vain enough to ask to be included in the picture. The main point I want to make here, however, is that the colours in this painting aren't just chosen according to what took Titian's fancy. They have a symbolic significance. To the priests and educated nobles who would look at this picture, the colours carry particular meanings, although these are usually lost on us when we view paintings like this today. For example, the fact that this old chap here is wearing blue and yellow robes tells us that he is St Peter: painters in Titian's time had colour codes for important people like the saints, so that viewers could tell who they were.

Now, what I want to explain to you tonight is that a lot of this colour symbolism comes from a question of chemistry. What the colours mean often depends on the chemical substances used to make them.

First, let's have a look at what colour is.

Scientists and philosophers and artists have argued about this for centuries. The ancient Greeks, for instance, used to believe that colour was an intrinsic property of an object. What I mean by that is, just as an object has a certain weight, size, texture, smell and so on, it was thought to have a definite colour. In many ways we still think like this. We say that we've got a blue coat, or a green bike, or a red car. But what colour is the coat when it's in the cupboard? What colour is the car at night? You might say, well, it's still red. But under a streetlight, it might not look red at all – more a kind of orange-brown, maybe. What colour is it in moonlight? You've probably all seen how difficult it is to tell the colour of some cars at night. But of course, you could say that their colour is precisely what you see, not what you think you ought to see if it was the middle of the day and not night time. So you see, colour is not just about what an object is made of; it is about how it is lit too. Colour is about light.

Even in ancient times, people knew that colour can be conjured up from light. When a sunbeam, which is generally invisible and seems to have no colour itself, passes through a thick piece of glass or a glass of water, it can produce colour [pic]. This is called a spectrum.

The spectrum contains the same colours as a rainbow, and in the same order. The Wizard of Oz acknowledges this. When Dorothy is whisked to 'somewhere over the rainbow', she goes from a black and white Kansas to a Technicolor Land of Oz.

The first person to explain where the rainbow's colours come from was Sir Isaac Newton, in about 1665. He did a clever experiment to figure out what the colours of the rainbow are and where they come from. Newton let a single shaft of sunlight come through a crack into a darkened room, and pass through a prism. A prism is a piece of transparent material shaped like a Toblerone – now we usually make them out of glass, but in Newton's day they were sometimes made from clear crystals like quartz. Now, people already knew that if you do this, you get a multicoloured spectrum. They thought that the prism must be doing something to the sunlight, somehow changing it to give it colour – like sending a car body through the paint sprayer on an assembly line so that it comes out coloured.

But Newton did something more. He passed the coloured light through a lens, which focused all the rays back together again. And he found that where they came together, there was a spot of white light, just like the one you get if you simply let the ray of sunlight fall onto a piece of paper. In other words, the beam of light coming through the crack already contains all the rainbow's colours, and all the prism does is separate them out. If you mix them all together again, you get back white light.

Then Newton did another experiment. He put a mask—a piece of card, say—in the way of the spectrum so that only one colour of light could pass: say, red. He then passed this light through another prism. If colour really does come from something that prisms do to light, you'd expect this red light to be altered somehow when it passes through the second prism. But it isn't: it emerges again as red light. You can't break down this red light into any more colours. The same with all the other bands in the spectrum. So these are the fundamental colours – they aren't themselves composed of any other colours.

Newton made a list of what these fundamental colours are. He claimed that he could see seven of them in the spectrum: red, orange, yellow, green, blue, indigo, violet. You might still get taught that these are the seven fundamental colours that make up white light. But actually, Newton was just making this up. Can you really see where blue ends and indigo begins, or where the division is between indigo and violet? Today, most colour scientists consider that there are only six colours here: instead of blue, indigo and violet, they just distinguish blue and violet, or blue and purple. Newton claimed there were seven colours not for any good scientific reasons, but because he thought that the colour scale ought to be like the musical scale, which has seven notes (do re mi…).

So Newton said that colour comes from light. He explained that a rainbow is formed when drops of rain in the air act like tiny prisms, each one splitting sunlight into its different colours. In theory, this creates an entire circle of coloured light; but in fact half of that circle is below the level of the ground, so we see just a semi-circular bow. [pic]

But if colour comes from light, what is light? Newton didn't really know, and nor did anyone else until about 150 years ago, when a scientist called James Clerk Maxwell discovered that light is a kind of wave. The waves on the sea are created from up and down movements of water. What is moving up and down in light waves? Maxwell showed that these waves are formed from up and down oscillations of electric and magnetic fields.

A magnet is surrounded by a magnetic field, and this field is what pulls two magnets together, just as the gravitational field of the Earth pulls on the moon and makes us stick to the Earth's surface. And when an object is electrically charged, there is a similar electric field all around it – this is what makes your hair get attracted to a comb after you've combed it (the movement of the comb through your hair makes them both electrically charged). Well then, light is like a ripple of an electric and a magnetic field: it is called an electromagnetic wave.

Every wave has a wavelength: this is the distance between two successive ripples. In waves on the sea, the wavelength might be as small as a few centimetres, or it might be several metres or even longer. For light, the wavelength is very short. It's this wavelength that determines what colour we perceive the light to be. Red light and green light, say are identical electromagnetic waves except for one thing: they have different wavelengths. For red light, this wavelength is about 700 millionths of a millimetre – that means there are about 140,000 waves in a single millimetre. For green light, the wavelength is shorter – about 500 millionths of a millimetre, so that there are about 200,000 waves per millimetre. And for blue light, the wavelength is shorter still. So all of a sudden, the difference between red and green, which seems huge when we're choosing a shirt, looks trivial: a tiny difference in wavelength.

And electromagnetic waves can have wavelengths longer and shorter than those of the light we can see. When the wavelength is shorter than violet light – less than around 400 millionths of a millimetre – the light is ultraviolet, or, as it gets shorter and shorter, X rays and gamma rays. When the wavelength is longer than that of red light, first we get infrared, and then microwaves, then radio waves, which can have wavelengths several kilometres long.

Now, let's look at how these differences in light create different colours in real objects. You see that all the colours of the rainbow already 'exist' in some sense, in ordinary daylight. What happens when this light falls on objects like our clothes, or an apple, or grass, or a car, is that some of that daylight gets absorbed and some gets reflected so that it can reach our eyes. [pic]

How does this happen? Objects are made up of molecules, and some of those molecules can vibrate in step with the electromagnetic waves of light. If that happens, they can soak up the energy of the light and absorb it. Let's say the molecules vibrate in step with red light. Then when sunlight hits the object, the red part of the spectrum gets absorbed. All the light that isn't absorbed gets reflected, and that's the light that reaches our eyes. So what we see is just the yellow, green and blue light bouncing off the object, and it looks bluish-green.

White objects don't absorb any light from the visible spectrum, so that it all gets reflected. Black objects absorb it all. In grass, there are molecules of a substance called chlorophyll. These molecules absorb blue and red light, and just reflect the green. So if we want to make an object or a substance of a particular colour, we have to look for a pigment or a dye in which the molecules have the right kind of vibrations, so that they absorb some colours and reflect the ones we want to see.

So Newton's explanation of colour all sounds very good, but there was one big puzzle. He seemed to be saying that if you mix all the colours of the rainbow together, you get white. But painters had been mixing colours for centuries, and they knew this wasn't true at all. Quite the contrary: if you mix all those colours, you get something pretty close to black. So some people decided that Newton's ideas were nonsense. They weren't, but the problem wasn't solved until Maxwell came along. He showed that mixing paint isn't like mixing light.

With paints, you can mix all the colours of the spectrum using just three primary colours: red, yellow and blue. But Maxwell built an instrument that let him mix different coloured light ways, and he found that a different set of mixing rules applied. The three primaries here were red, blue and green. You may know that these are the colours of the little glowing pixels that cover your TV screen. With light of these three colours, you can mix up just about any other colour. And whereas mixing the three paint primaries makes black (or something close to it), mixing the three primary colours of light makes white. These two different ways of mixing colours – by mixing paints or dyes, and by mixing light – are called additive and subtractive mixing. Painters got confused by Newton because he was talking about additive mixing, whereas they used subtractive mixing.

So you see the science of colour and the art of colour have sometimes seemed to be at odds with one another. And after all, artists and craftspeople had been making colours for centuries before Newton came along. They didn't really need to understand colour in all this technical detail – what they wanted were ways of creating colour. That's what I want to look at now; and I want to show you that our attitudes to colour – the way we feel about it – have been strongly influenced by the technology we've used to make it.

[Look at tubes of modern paints: what's in them? They are complex chemicals invented only in the past 100 years or so.
Go back to Titian's Pesaro altarpiece – he had brilliant colours, but they were made mostly from very different materials than modern paints.]

The earliest colours had two natural sources: minerals and living things, mostly plants. Titian's blue sky, for example, was made from a blue mineral ground up into a powder and mixed with oil to make a paint. The woad of the ancient Britons came from a plant. Getting it out of the plant wasn't a very pleasant process. Basically you mashed up the plant in water and let the mixture ferment. To help it ferment, it was typically mixed with urine and left out in the sun. Sometimes this mixture would be trampled underfoot to help release the dye. And not surprisingly, it stank.

The Romans also used a blue in their armies: they painted their parade shields with a substance called indigo. This word comes from the Latin word for the blue colouring agent: *indicum*. The Romans called it that because they imported it from India, where it was also made by fermenting a plant. Newton named the colour indigo in his rainbow spectrum after the colour of this indigo substance. Both woad and indigo contain a molecule that absorbs most of the spectrum and reflects only indigo-coloured light. And you know know what? The molecule in indigo is identical to the molecule in woad. The Romans and the Britons went to battle in the same colour, but they didn't know it.

And here's something even more ironic. The precious purple dye used by the Roman emperors was extracted from shellfish in the Mediterranean Sea. Each shellfish, when squeezed or crushed, gave no more than about a single drop of the dye. So hundreds of thousands of them had to be caught and crushed to extract enough dye for the imperial robes. This dye was discovered by a race of people called the Phoenicians, who lived in a region that today is part of Turkey. Their capital city was called Tyre, and the purple dye became known as Tyrian purple. It was because this dye was so hard to extract that it was so precious.

Well, of course the Phoenicians and the Romans had no idea what chemical caused this lovely purple colour. But when chemists studied it about 100 years ago, they found a remarkable thing: it was almost identical to the chemical that gives woad and indigo their blue colour. Chemically speaking, the only thing that distinguishes the Britons' barbaric woad blue from the emperor's royal purple are two extra atoms of bromine on each of the molecules.

Purple remained a hard colour to make until about 150 years ago. In medieval times, people forgot the secret of making Tyrian purple, and they had to find other sources of it. In Europe, a purple dye was extracted from certain mosses and lichens. But these dyes weren't very good – they faded quickly in sunlight. There was also something strange about them. Dye makers found that sometimes they got a reddish colour, sometimes purple, and sometimes blue, depending on exactly how they extracted the substance. They discovered that they could *change* the colour using chemistry. It worked like this.

[Cabbage juice, with acids and alkalis]

You've probably seen this kind of colour change already. It's the same thing that happens to litmus paper. The litmus test is used to tell if something is acidic or alkaline; litmus is called an indicator. The chemist Robert Boyle, who lived at the same time as Isaac Newton, investigated how colours were made, and he suggested that these purple dyes from moss and lichen could be used as chemical indicators. In fact, litmus is one of them: it is extracted from a Scandinavian lichen.

So the importance of colours once depended on how hard to make, and so how expensive, the dyes were that were used to produce them. In the Middle Ages, good red dyes were hard to find. The best of them was cochineal, which was made from crushed insects that live on cacti in South America. Europeans didn't have this dye until the Spanish and Portuguese began to travel to America in the sixteenth century. The finest red dyes like this were reserved for the most important people in society: the popes and cardinals. [pic – Raphael's Leo X]

Many of the wealthy merchants, on the other hand, wore black clothes. [pic] Today this makes them seem very sober. But the truth is that black was a hard colour to make. Some clothes would be dyed black by dyeing them in several bright colours in succession: mixing yellow, red and blue, as we saw earlier. But using all these dyes made black cloth expensive. So merchants wore black to show off how wealthy they were. It wasn't necessarily a sober colour at all, but a boastful one.

This difficulty of making colours meant that there wasn't a big choice. It wasn't until the nineteenth century that chemists started to find ways of making dyes artificially. They made them from chemicals that can be extracted from the oily residue left behind when coal was used to make gas for gas lighting. Here are some of the first of these synthetic dyes – the very first was this gorgeous purple, called mauve. They meant that people began to wear very richly coloured clothes, as you can see in this painting from the middle of the nineteenth century. This was how the modern chemical industry began – many of the big chemical companies today started by making artificial dyes for colouring textiles. [pic – Bayer]

As all these new colours started to appear, they had to be given names. How do you do that? Everyone knows red or yellow or blue when they see it, unless they have colour blindness. But can we agree on other colours?

[Show some, and get opinions on how to describe/name them]

So you see, it gets hard to talk about colours unless we have a language for them. But we don't have a language that covers all the possible colours, largely because most of these shades just haven't been around for long enough. What happens is that colour makers, like paint companies, simply invent artificial names that give only a vague clue about what the colour is. [Dulux chart – ask people if they can put colours to names]

But naming colours can be even more complicated than this. Different cultures sometimes have different ideas about how to identify and classify colours. The English artist Derek Jarman once owned a bright green coat that everyone admired, but he explained to his friends that in Japan, where he'd bought it, it had been sold as 'yellow'. Japanese also has a colour word *awo* (pronounced ah-oi) which can sometimes mean what we'd call blue, and sometimes green. Sometimes it just means 'dark'. There's a similar word in Welsh, an old Celtic word, *glas*, which means 'the colour of mountain lakes'. It can be almost any colour between brownish green and blue. In Russian there isn't really a word for 'blue' at all, but two words, one for light blue and one for dark blue. Some languages use the same word for blue and yellow – imagine that. And some have hardly any words for colours at all. A language called Hanunoo, spoken by some people in the Philippines, has four colour words. Two of them mean more or less the same as our black and white, or dark and light, but the other two can't really be translated as colours at all – instead, they mean something like 'fresh' and 'dry'. And even here in France you might find that colour words don't always translate directly into English words: hair that is 'brun' isn't necessarily brown, but just dark, while you'd never call some brown things *brun* (like shoes), but instead have to use another word like *marron* or *beige*.

All this reminds us that when we talk about colour, we are talking about many different things at once. There's the question of how colour is made by light, which is a matter of physics. There's the question of colour-giving molecules, which is a matter of chemistry. Our attitudes to colour can be strongly affected by the technology used to make it. There is the entire issue of how our eye and brain transform light rays into a perception of colour, which I haven't had time to talk about; that is, the biology of colour. The way we experience colour is also influenced by colour relationships – colours look different depending on what colours they are placed next to [pic]. And we have seen that colour has symbolic meanings, which artists often use. Colours seem to have emotional effects: some are soothing, some are jarring and disturbing. And there are many cultural factors that influence our responses to colour, because colours may mean different things to different cultural groups, who might even chop up Newton's spectrum in very different ways.