

## Colours, light and shadow

The "Make You Wonder" experiments in this project are developed after visiting the exhibition "Innen Stadt Aussen" by the Danish-Islandic artist Olafur Eliasson at the Martin Gropius-Bau in Berlin 2010.

Olafur Eliasson worked with light and shadows using white and coloured spotlights in rooms so big that the visitors themselves made the shadows when moving around in the room. Interesting effects appear, making the visitors wonder!

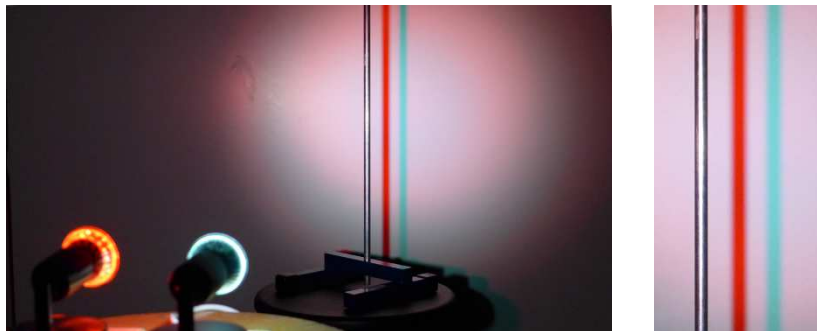
Small-scale version of the Olafur Eliasson exhibition:



Shades of grey, produced by 3 white spotlights when a person moves into the space between the spotlights and the white background



Coloured shadows, produced by 3 coloured spotlights when a person moves into the space between the spotlights and the white background












Red and cyan shadows produced by red and white spotlights

In the matter of physics, the first lessons should contain nothing but what is experimental and interesting to see. A pretty experiment is in itself often more valuable than twenty formulae extracted from our minds.

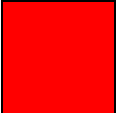


Albert Einstein in  
Einstein the Searcher,  
by Alexander Moszkowski, 1921


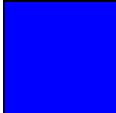

## Station 1 Additive colour mixing

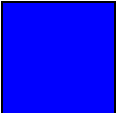
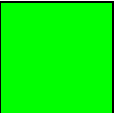

	Hypothesis The colour will be	Experimental result The colour is	Hypothesis Verified or falsified?
 + 			
 + 			
 + 			
 +  + 			

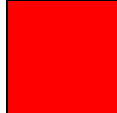
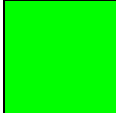
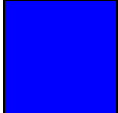

Explanation

## Colour mixing on a computer (see e.g. [www.oms.edu/tech/colormix.php](http://www.oms.edu/tech/colormix.php))

	+		=	
R =		R =		R =
G =		G =		G =
B =		B =		B =

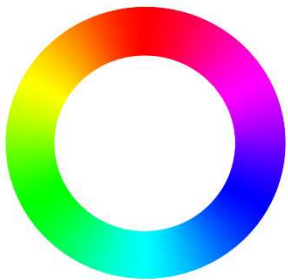
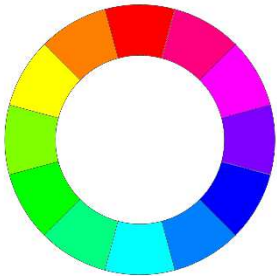
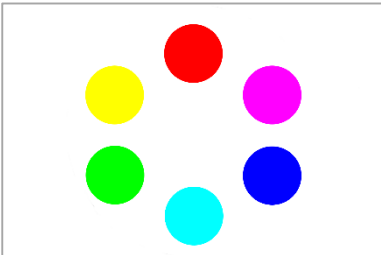
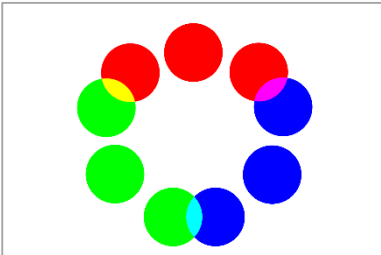
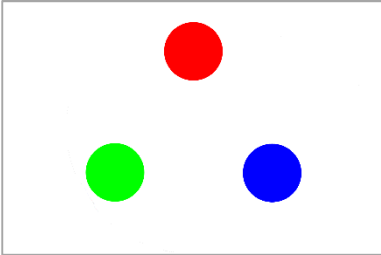
	+		=	
R =		R =		R =
G =		G =		G =
B =		B =		B =

	+		=	
R =		R =		R =
G =		G =		G =
B =		B =		B =
















	+		+		=	
R =		R =		R =		R =
G =		G =		G =		G =
B =		B =		B =		B =

Explanation

# The Colour Circle




## Station 2 Coloured shadows

	Hypothesis The shadows will be	Experimental result The shadows are	Hypothesis Verified or falsified?
 + 			
 + 			
 + 			
 + 			
 + 			
 + 			
 +  + 			

Explanation


## Complementary colours on a computer

Basic colour



R = 255  
G = 0  
B = 0


Complementary colour



R = 0  
G = 255  
B = 255


=

The complementary colour is an additive mixture of these colours




R =  
G =  
B =

+




R =  
G =  
B =

Basic colour



R =  
G =  
B =


Complementary colour



R =  
G =  
B =


=

The complementary colour is an additive mixture of these colours




R =  
G =  
B =

+



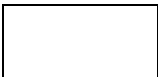
R =  
G =  
B =

Basic colour



R =  
G =  
B =

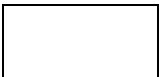
Complementary colour



R =  
G =  
B =

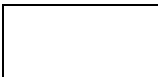
=

The complementary colour is an additive mixture of these colours



R =  
G =  
B =

+



R =  
G =  
B =

### Station 3 Afterimages

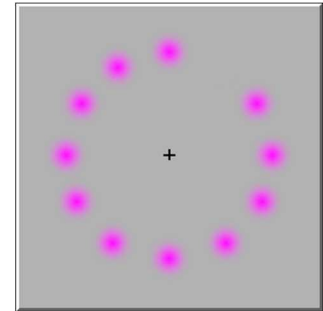
Look at the black cross in the centre of the picture (on a computer screen, with the picture shown as a .gif-picture).

**Question:**

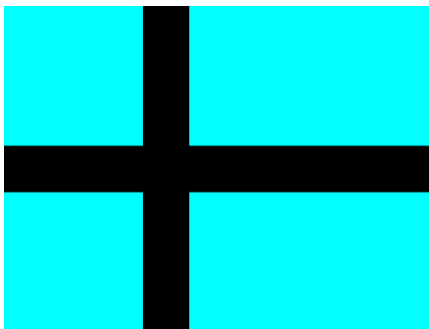
Do you see magenta dots all the time?

**Answer:**

If not, the answer might be *afterimages* in the complementary colour.



Afterimages are seen when you look at a coloured object for a long time, and switch to a white background (on a computer screen, e.g. as a picture in a Power Point Presentation, which makes it easy to switch from the picture to a white screen).



Explanation



Explanation

## Statin 4 Colour vision 1

Colour vision is possible because of the three different types of cone cells in our retina, named L, M and S (for Long, Medium and Short), depending on the wavelength of their peak sensitivity.

A specific wavelength is detected because the different cone cells detect different amounts of photons.

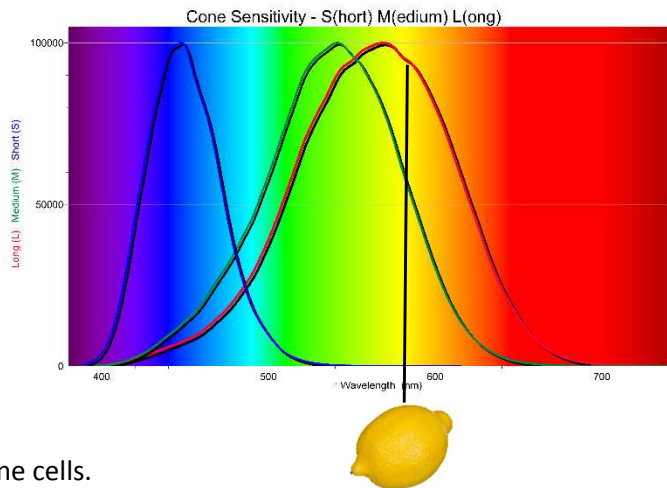
**Question:**

What makes a lemon look yellow?

**Answer:**

The reflected light from the lemon hits M and L cone cells.

**Our brain understands this as seeing the colour yellow.**



**Question:**

What makes an orange look orange?

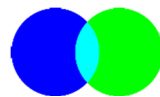
**Answer:**

## Station 4 Colour vision 2

Compare the result of additive colour mixing with the wavelengths of the visible spectrum.

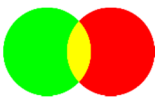
Mixing **blue** and **green** gives **cyan**.

Cyan is placed between blue and green in the visible spectrum

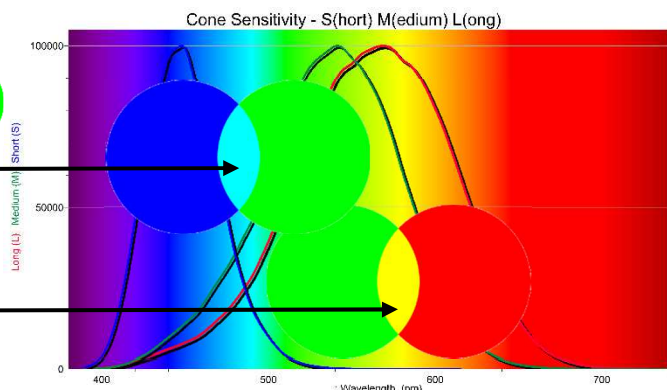
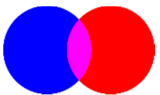


Mixing **green** and **red** gives **yellow**.

Yellow is placed between green and red in the visible spectrum.



Mixing **blue** and **red** gives **magenta**.



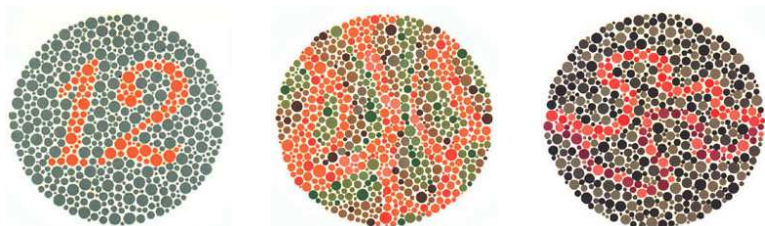
**Question:**

Magenta is a colour you don't see in the visible spectrum!  
What makes it possible for us to see the colour magenta?

**Answer:**

## Station 5 Colour blindness

If your cone cells doesn't respond in "the normal way", your colour vision might be disturbed, giving red-green or other types of colour blindness.



Result of the test?

Comments to the test:

### How the test works:

For each plate you have to either enter the number or you have to choose the number of lines you can see. If you don't see anything just leave the input field empty.

Find the Ishihara 38 Plates Test here: <http://www.color-blindness.com/ishihara-38-plates-cvd-test/>

## Station 6 The Bohr Model of the Hydrogen Atom

The Bohr model explains in a simple way how emission and absorption spectra are produced.

### Emission spectrum

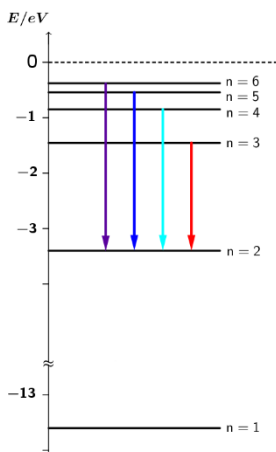
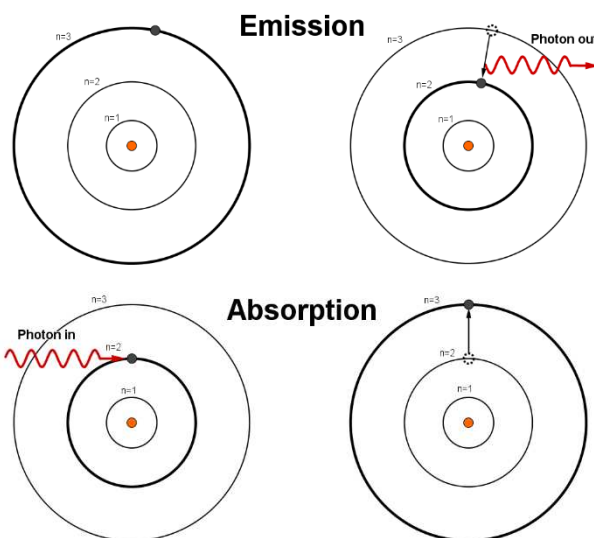


Emission lines are seen when an electron jumps from a "higher" to a "lower" state.

### Absorption spectrum

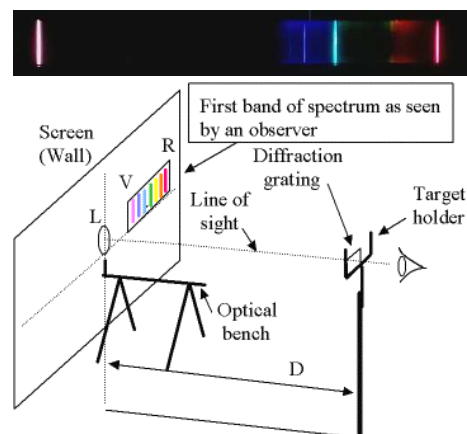


Absorption lines are seen when an incoming photon "forces" the electron to jump from a "lower" to a "higher" state.



**Left:** The four visible lines in the Balmer Series of the Hydrogen Spectrum

**Right:** Hydrogen spectrum, photographed with a smartphone through a diffraction grating with 600 lines/mm



[www.pstcc.edu/departments/natural\\_behavioral\\_sciences/Web%20Physics/Exp%2008.htm](http://www.pstcc.edu/departments/natural_behavioral_sciences/Web%20Physics/Exp%2008.htm)

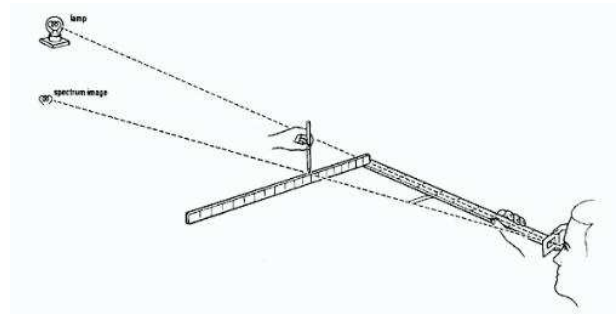
## Station 7 Diffraction and gratings

Diffraction is a part of the physics course, but not a part of the basic science course. However, the grating equation is needed to calculate wavelengths.

The grating equation

$$n \cdot \lambda = d \cdot \sin(\varphi)$$

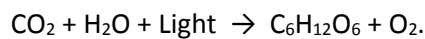
The students discover the meaning of  $n$ ,  $d$  and  $\varphi$  in the grating equation using cheap laser pointers and gratings with different values of  $d$



[practicalphysics.org/measuring-wavelength-light.html](http://practicalphysics.org/measuring-wavelength-light.html)

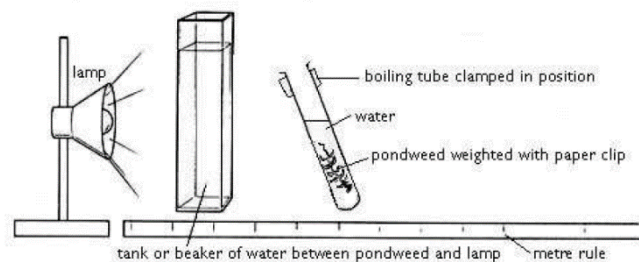
## Station 8 Photosynthesis

The photosynthesis process:



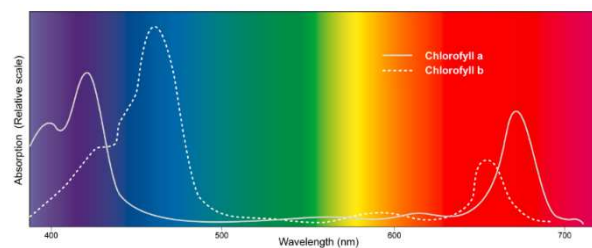
Light is needed. Use light with different colours and measure the rate of photosynthesis by counting the number of bubbles rising from the cut end of a piece of Elodea.

If you use LED-spots, you do not need the tank with water between the light source and the boiling tube with the pondweed.



[www.nuffieldfoundation.org/practical-biology/investigating-factors-affecting-rate-photosynthesis](http://www.nuffieldfoundation.org/practical-biology/investigating-factors-affecting-rate-photosynthesis)

- 1) Use the Chlorophyll Spectra to the right to make your hypothesis.
- 2) For each colour, count the number of bubbles rising from the cut end of a piece of Elodea.



	Hypothesis What will happen with this colour of the light?	Experimental result What happened with this colour of the light?	Hypothesis Verified or falsified?
White light			
Blue light			
Green light			
Red light			