Notes for teachers

on module 2:

Colours

Colours catch our attention. Just as marketing specialists use colourful advertisement to draw your attention to some kind of product, you can use the attractiveness of colours to draw your student's attention to your science lessons.

You might find that this module introduces colours in a different way than do most schoolbook authors. The worksheets do not aim at "explaining" the phenomena of colours, but rather use the topic to make students familiar with the scientific method. Students have to choose a hypothesis, design and conduct their own experiments, distinguish between observation and interpretation of their experimental results, and give evidence for their conclusion. Please allow your students enough time to make their own research discoveries, and, if necessary, for some detours. The most valuable lesson may be learned by students proving their own hypothesis wrong.

Summary: Students will learn how colours are created and how they are mixed.

The module is structured in two chapters:

- Rainbow colours: Students find out how colour filters work and use them to study the cause of the colours of the rainbow.
- Colour mixing: Subtractive colour mixing is illustrated with colour printing, while additive colour mixing is demonstrated with computer screens.

Designed for: lower secondary level (age ca. 12 to 14)

Duration: Each chapter is designed for ca. 80 min.
in total 4 lessons or 160 min

What students should already know:

- Humans see an object because light from the object enters the eyes.

What students will learn:

Facts

- Sunlight includes all colours of the rainbow
- The colours in white light can be split apart, e.g. by refraction
- Colour filters and coloured objects appear coloured because they absorb parts of the visible spectrum
- Additive colour mixing, illustrated with computer screens
- Subtractive colour mixing, illustrated with colour prints
- Colour is a perception

Skills

- Working with the scientific method
- Designing experiments to provide evidence for a hypothesis
- Distinguishing between observation and interpretation of experimental results

This module includes:

- 2 worksheets
- 2 fact sheets

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Chapter 1 | The secret of rainbow colours

Suggested lesson outline

Students look for different ways to generate rainbow colours and are asked how these colours are created. They find out how colour filters work and use them as a tool to see that white sunlight includes all colours.

Timing in minutes	**Activity**	**Material**
	First lesson	
0 – 10	Introduction	
10 – 40	Group work on the WS "The secret of rainbow colours"	WS02.1 Colour filters *Not included in the kit:* CDs (might get scratched!)
	Second lesson	
0 – 20	Second lesson: continue the group work on the WS	Ditto
20 – 40	Hand out and discussion of factsheet	FS02.1 Colour filters

Description of suggested lesson

Preparation

Although the worksheet includes colour pictures, it is not mandatory to print it in colour. The factsheet, on the other hand, should be handed out as a colour print-out (at least one colour copy per group).

You will need a set of CDs for the experiments in this module. Please keep in mind that after the lessons these CDs will most probably not be usable any more to store data.

A block period of two lessons is recommended for this chapter.

Introduction

Start the lesson by having your students describe their own experiences with rainbows. Ask them if they like rainbows and what they already know about them. Then tell your students that in the following two lessons you will work together to discover the origine of rainbow colours.

Worksheet "The secret of rainbow colours"

Please hand out the worksheet "The secret of rainbow colours" (WS 02.1). Ask a student to read the introduction and another to read the first task (Point 1) to the class. Once the students understand the task, have each group separately look for ways to make rainbows. While some groups are still working on Point 1, you can ask your faster students to work on Point 2.

Then, in a class discussion, encourage the students to demonstrate some of their suggestions to make rainbows. Ask your students to observe these experiments carefully, as they might see things that help them later in discovering the cause of the colours in a rainbow. If a lack of sunshine prevents all experiments being conducted in class, you can still discuss with your students where they have already seen rainbows, e.g. in nature or at home.

After each group has worked on Point 2, read with your students the small text on the top of the second page. Have the groups clear their desks and place a white sheet of paper on it. The rule mentioned in the worksheet

should help to reduce the number of colour filters that disappear between the pages of school books or notebooks. Hand out a set of colour filters and a CD to each group and let them work independently through the rest of the worksheet.

Some students tend to peak at other group's work or might even directly ask what should be written as answers on the worksheet. Explain to your class that the worksheet is not an exam with only one right answer per question. Different experiments might lead to the right conclusions, and the questions are there merely as a help to guide the students to find the cause of rainbow colours as result of their own research work. Furthermore, the quality of an experiment depends not only on the way it is planned and conducted, but also on the quality of observation and a clever and critical interpretation of the experimental results. The weakest link in this chain determines the quality of the whole research work.

In Point 5, students are asked to come up with an experiment that provides evidence for the hypothesis they have chosen in Point 4. Go from group to group and discuss what they understand as "evidence". Make sure that this important concept in scientific work is well understood by all your students.

On the second page of the worksheet, students should discover that colour filters absorb a part of the white light. The remaining light, which passes through the filter, appears as coloured. If you note that a group has difficulties with Task 8, help them with guiding questions.

On the third page, students, with the help of the CD, can see which part of the visible spectrum or "rainbow colours" the different filters absorb (Point 9 and 10). This should allow the students to draw the conclusion that the rainbow colours are all included in white sunlight, and in turn, that white sunlight is the combination of all the colours of the rainbow. You won't find a question on the worksheet that specifically emphasizes this finding as this would give away too much for students who read ahead in the worksheet. Thus, please discuss this aspect with each group individually while they work on Point 10 of the worksheet.

The tasks in Point 11 and 12 are intentionally made more challenging than the previous questions. One reason is to give slower groups the chance to catch up with faster groups. The other, even more important reason is to give your students the opportunity to once again apply the scientific method. Some groups might immediately choose the right hypothesis, namely that the surface of a CD splits up the colours of white sunlight in different directions, while others might follow different ideas. Independent of the hypothesis each group chooses, ask them to either provide evidence for their conclusion based on the experiments they have already done, or to design new experiments to test their hypothesis. If their arguments shows any weaknesses, help the group identify those issues themselves and let them work on clarifying them.

Discussion of the Fact Sheet "The secret of rainbow colours"

Hand out the factsheet and have a student read the text up to the section "Facts to remember". Have the class discuss how the experiments conducted during the lessons could support the statements in the text.

Please note that the factsheet focuses on rainbow *colours,* rather than the specific example of rainbows caused by raindrops. However, if your students are interested enough to go further on this topic, ask them why the blue colours are on the top in the drawing on the upper right side of the page, while the red colour is at the bottom of the colour fan that leaves the raindrop. If you compare this with photos of (primary) rainbows from rainclouds, you will notice that the red bow is always seen above the blue bow. The illustration below may assist in explaining this effect. Help your students understand that a rainbow consists of the light from countless raindrops and that the colour of each drop primarily depends on the angle that we see it relative to the sun.

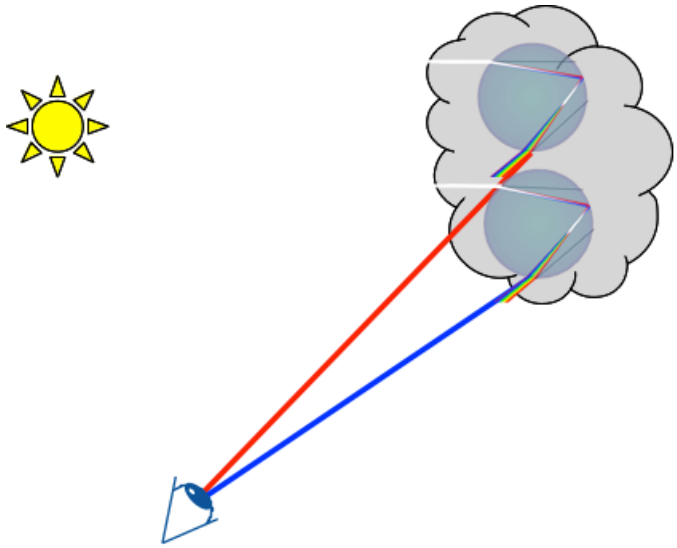

Figure 1: The red colour appears above the blue colour in a primary rainbow

If you decide to discuss rainbows in more detail, an interesting homework for your students might be to explain why the rainbow appears as an arc. Your students can find an abundance of resources available to support their research. They may then choose to explain the arc shape in writing, or in a drawing or as a model.

Please reserve sufficient time to discuss the ”Facts to remember” with you students. How would your students explain and prove the three statements to another student who had not followed the lesson?

Background information

Rainbow colours

In this module, the term ”rainbow colours” refers to the visible spectrum of electromagnetic radiation. This simplification allows you to work with spectral properties of light without introducing the concept of wavelengths or the wave character of light.

You might have noticed that the worksheet repeatedly refers to white *sunlight*. The use of sunlight is recommended instead of room light because most light sources such as fluorescent light tubes, compact fluorescent light bulbs (often referred to as ”energy saving light bulbs”), or white LED’s do not have a continuous spectrum. This is needed to conduct the experiments described in the worksheet. A more detailed study of this phenomenon is made in the worksheet WS07.3 in the module ”Diffraction and Interference” (designed for older students).

Rainbows

You will find numerous websites providing valuable information, illustrations, or even animations to explain the physics of rainbows in any desired amount of detail (e.g. http://www.atoptics.co.uk/bows.htm). As there is an abundance of available material, this document does not include yet another discussion of the phenomena.

Raindrops and CDs

To be accurate, the physical effects that split the light in a raindrop and on a CD are not the same. In a raindrop, or a prism, the angle of refraction (change of direction when entering the glass or water) depends on the wavelength (colour) of the light. The strength of refraction, in turn, depends on the difference in speed of light before and after entering an optical medium like glass or water. Although all visible wavelengths are roughly 30% faster in air than in water or glass, each wavelength has a slightly different speed in these media. This effect, called ”dispersion”, causes different wavelength to leave the raindrop at different angles, and thus the splitting of the rainbow colours.

On a CD, on the other hand, the colours are split due to diffraction and interference. The details of this phenomenon are discussed in the teacher notes of module ”Diffraction and Interference” (M07) in Chapter 3.

However, this distinction is not important for the educational objectives of this module,.

Students might ask

1) What happens to the light that the colour filter absorbs?

Light is a form of energy, and when it is absorbed, it is transformed into another form of energy. In the case of colour filters, the absorbed light is transformed to heat and therefore heats up the material.

To illustrate this effect, you could remind your students that they can feel strong sunlight on their skin. Just like the colour filter, the skin absorbs a part of the light and makes us feel warm. Sunscreen protects the skin by acting like a colour filter: tiny particles in the lotion absorb (or reflect) the invisible UV light before it can damage our skin.

2) Can a colour filter let pass light of different colours?

While conducting the experiment described in Point 9 and 10 of the worksheet, your students might note that the spectrum seen through a colour filter is not monochromatic. Through a blue filter, for instance, one can also see a bit of green and indigo light. This is also depicted in the factsheet, where both the light passing a colour filter and reflected from a coloured objects are not monochromatic.

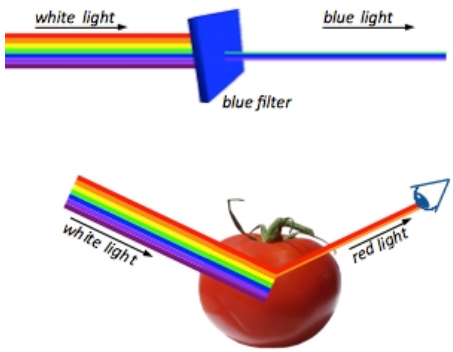

Figure 2: The blue light from a blue colour filter and the red light reflected from a tomato are not monochromatic [FS02.1]

The immediate answer to the student’s question is: “Yes, a colour filter can be designed such that it absorbs selected parts of the rainbow colour spectrum. The engineers can even determine how much of each colour is absorbed.”

However, your students should find the answer to this question themselves in the worksheet ”Getting the colour right”. It is recommended that you bring this question up again when discussing the factsheet in the next chapter.

Chapter 2 | Getting the colour right

Suggested lesson outline

Students will mix colours to match the eye colour of a classmate as accurately as possible. They then study how colours are mixed in offset and inkjet printing as an example of subtractive colour mixing. Additive colour mixing is illustrated using a computer screen. At the end of the chapter, students get to know that colours are a perception and that the most important colour mixing process actually happens in their brain.

Timing in minutes	**Activity**	**Material**
	First lesson	
0 – 10	Introduction	
10 – 40	Individual and group work on the first page of the worksheet "Getting the colour right" Subtractive colour mixing	WS02.2 Colour filters Lenses (f=30 mm) *Not included in the kit:* Colouring tools, e.g. crayons
Homework, *or as additional lesson*	Second page of the WS: Additive colour mixing	WS02.2, *Not included in the kit:* Computer Strong magnifying glass
	Second lesson	
0 – 10	Discussion of homework	WS02.2
10 – 30	Group work on third page of WS: primary colours	WS02.2, Colour filters Lenses (f=30 mm)
30 – 40	Hand out and discussion of factsheet	FS02.2 Colour filters

Description of suggested lesson

Preparation

Although the worksheet includes colour pictures, it is not mandatory to print it in colour. The factsheet, on the other hand, should be handed out as a colour print-out (at least one colour copy per group).

The second page of the worksheet requires a computer with colour monitor and some software that features a colour selection menu. You may choose to work on this part in class, using the computer facilities of your school, or to let your students work on Points 6 to 10 at home. If you intend to use the facilities of your school, it might be necessary to reserve access to these facilities in advance.

Optional: You might want to consider aligning the teaching of this chapter with your colleagues who teach fine arts to the same class. The different perspectives on colours will enrich the experience of your students.

Introduction

Ask your students to name their favourite colour. Once a few students have answered, ask them why they prefer their respective colour to others. When your students are engaged in the discussion, direct their

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attention to the question of how all these different colours are ”made” (e.g. pointing out some examples). Your students will probably suggest that by mixing colours one can generate new ones. Let your students know that in the following lessons they will learn two principal ways of mixing colours.

Subtractive colour mixing – colour printing

Please hand out the worksheet “Getting the colour right” (WS02.2). Have your students read Point 1 of the worksheet and make sure that they understood the task. Then give them 5 to 10 minutes to complete it. It is recommended that you clearly communicate the time limit before your students start. While your students are working on colouring the eye, you can explain to them that the iris of each eye is so unique that iris scans are used to identify a person. This is no longer limited to science fiction movies, but used as a contact-free alternative to finger prints. However, like all biometric personal identification techniques, it also includes certain risks. Students who finish the task faster than their classmates might thus engage in a discussion about the pros and cons of iris based person recognition.

After your students have completed the first task, ask them how many different colours they mixed to achieve the desired result. Then show them a photo print in a book, or point it out to them, in case they all have the same book. How are such photos printed? Keep the question open, hand out the lenses with f=30mm that will serve as magnifying glasses. For the rest of the lesson, let your students work in groups to answer the questions 3 to 5 on the worksheet. After your students finished the page, you may use the following illustration (projected on a screen or as printout) to explain the colour mixing technique used for printing:

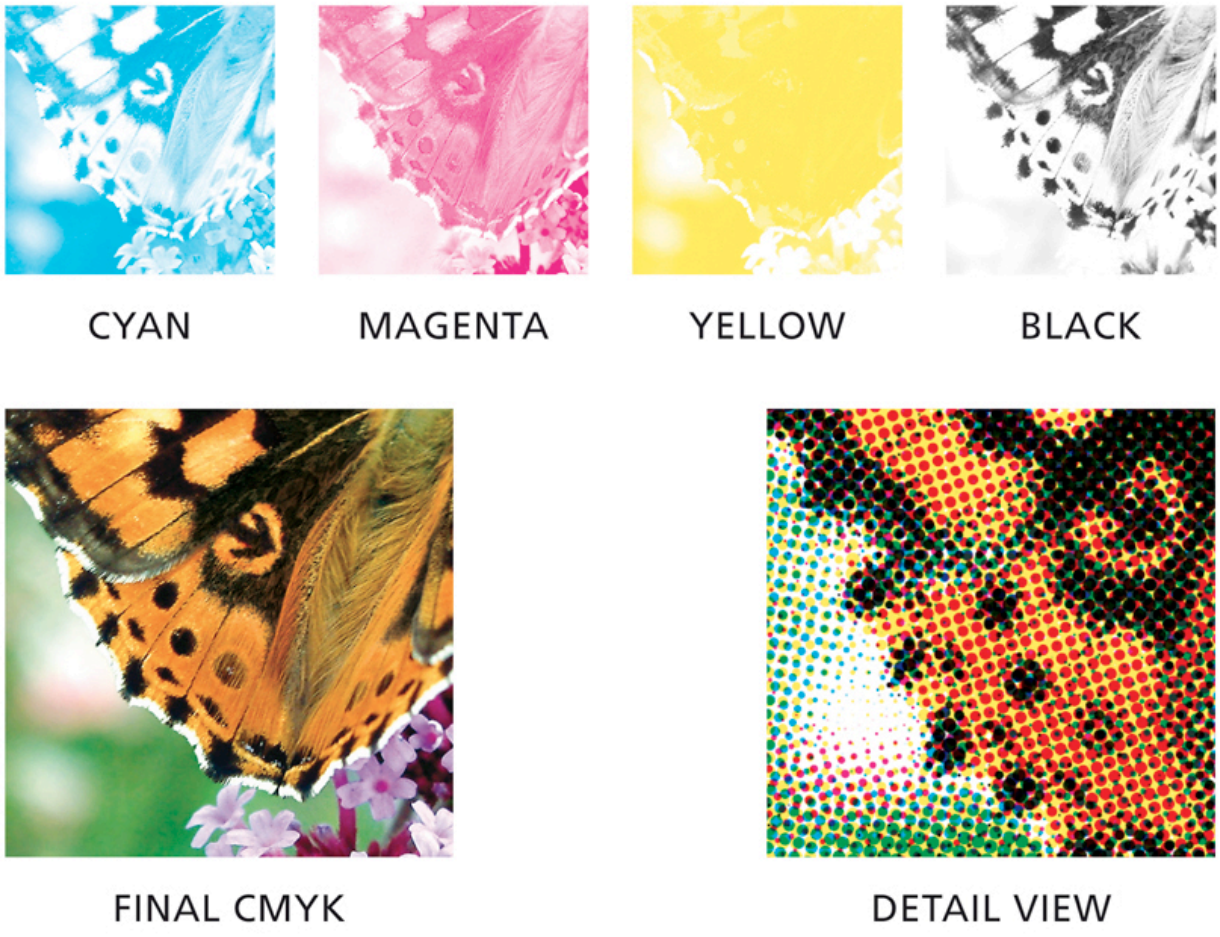

*Figure 2: Colour prints consist of small dots in **c**yan, **m**agenta, **y**ellow and blac**k** (abbreviated as CMYK).*
[Image copyright of Document Services, University of South Australia; may only be used for educational purposes]

Most colour prints we see, either in books, magazines or on product packages, are actually four prints, aligned exactly on top of each other. Each print has a different colour, namely cyan, magenta, yellow and black. In all four prints, the amount of ink, and thus the intensity of the respective colour, is locally controlled by varying

the sizes of small dots in a regular raster. Obviously, it is very economic to print just these 3 colours together with black to generate the entire spectrum of colours we see in such a print. At the end of the chapter, the students will find out how this is possible.

Additive colour mixing – computer screens

The second page of the worksheet focuses on additive colour mixing using computer screens as an example. If you choose to let your students work on this topic at home, please ensure that each student has access to a computer with suitable graphics software. The help of parents or other family members is welcome and will not reduce the learning effect, but rather stimulate it. Nonetheless, the second page of the worksheet can also be handled in class given that your school has suitable computer facilities.

Many computer programs offer some kind of colour selection menu. However, these menus are usually more elaborate in photo-editing software. Furthermore, the use of photo-editing software allows your student to play freely with different colour tools that the software offers and to see the result on a sample picture of their own choice. This has a three-fold benefit: The students get a better feeling for colours, learn about colour mixing in the context of a real-world application relevant to their life, and have fun. If no photo editing software is installed on the computer, your students could use free software like ”gimp” (http://www.gimp.org/) that runs on all common operating systems.

Figure 3 shows a magnified region of a computer screen and gives you an impression of what your students will see through the magnifying glass (the depicted screen has a matt surface to improve the visual impression of the observer, which causes the slight inhomogeneities). The photo shows that each pixel consists of one red, green and blue stripe. If all three stripes are adjusted at maximum brightness, the pixel appears white. If all three stripes are dark, the pixels appear black. All other colours are mixed by adjusting the relative brightness of the stripes.

Figure 3: Pixels of a computer screen.
The photo shows a black “[“ followed by blue letters ”ed” on a white background.

To complete the table in Point 9 of the worksheet, it is sufficient to note down the values for red, green and blue. However, some students might have decided to record all parameters they see in the menu. Discuss with your students the meaning of each parameter – either while the students work on Point 9 in class or when reviewing the homework (see background information, ”Colour selection menu”). A filled-in table for Point 9 might be as follows:

Colour	R	G	B
Red	255	0	0
Green	0	255	0
Blue	0	0	255
Cyan	0	255	255
Magenta	255	0	255
Yellow	255	255	0

The answer to the question raised in Point 10 is given in the factsheet. Please *do not yet comment on this question,* as the students will continue to work on this topic on the third page of the worksheet.

Primary colours

The third page of the worksheet focuses on the importance and connection between the primary colour triplets [red, green, blue] and [cyan, magenta, yellow]. The rather quick series of experiments demonstrates the role of these colours in subtractive and additive colour mixing. Point 15 raises a very similar question as Point 10, but is a bit more specific. Once your students have reached the end of the worksheet, you can use a class discussion of Point 15 to make the transition to the factsheet.

Please note: due to a manufacturing error in the LED module, the red LED is weaker than the blue and green LED's. The results of the experiments in Point 13 and 14 will therefore not be as clear as they should be, until an improved series of modules is used in the Photonics Explorer kit.

Discussion of the factsheet

Please hand out the factsheet as a colour print-out. This page summarizes the findings of the worksheet and provides answers to the previously raised questions. It also introduces the terms "additive colour mixing" and "subtractive colour mixing". The student should be familiar with these terms although they are not needed during the work on the worksheet.

Have a student read the introduction of the factsheet to the class. Take some time to discuss the point that colours are a perception and why it can be said that colours "happen" in the brain. To see if they understood the point made in these two paragraphs, you can encourage them to explain the last sentence with an example.

After you discuss with your class the "Facts to remember" and the answer to the questions raised in Point 10 and 15 in the section "The connection…", invite your students to test the anaglyph in the right bottom corner. If they follow the instruction, they should see a 3D effect in the picture. You can explain that humans see in 3D because our left and right eye see slightly different pictures from their respective perspective. It is again our brain that combines the information from both pictures into a 3D impression. When we look at normal colour prints both eyes see the same picture. However, in the anaglyph, two pictures are printed on top of each other: the perspective of the left eye in red, and the perspective of the right eye in cyan. With the corresponding colour filter before each eye, we only see the picture from the left-eye's perspective for the left eye and the same scene from the right eye's perspective for the right eye. You can find many more examples of anaglyphs on the Internet that you might want to project or print for your students.

Background information

You will find additional information on the topic of vision in the background information of the teacher notes of the module ”Eye and vision”.

Colour selection menu

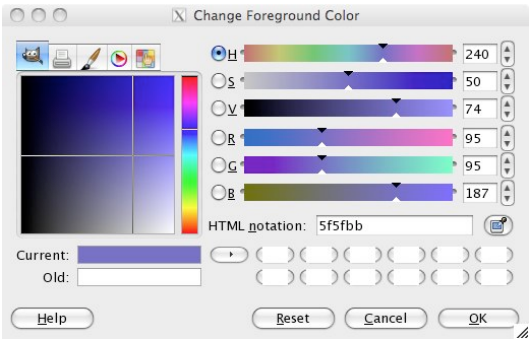

Figure 4: colour selection menu for photo editing software

The layout of the colour selection menu can differ depending on the software used. Most menus feature more than one representation of the selectable colours. However, virtually all decent colour selection menus offer the following parameters to adjust the desired colour:

The letters ”R”, ”G”, and ”B” stand for red, green and blue, respectively. By varying these values, you can directly set the relative brightness of the corresponding stripes in the field ”Current” (the field that shows the currently selected colour) between 0 corresponding to dark and 255 corresponding to the maximum brightness.

The letters ”H”, ”S”, and ”V” stand for ”hue”, ”saturation” and ”value”. The combination of these three parameters is simply another, arguably more intuitive, way of describing a colour. Consequently, these parameters change automatically when the user changes the selected colour. While the RGB triple describes colours in a Cartesian coordinate system, HSV represents colours in a cylindrical coordinate system. The value ”hue” (“H”) stands for the angle, such that the parameter options create a circle (maximum and minimum value describe almost the same colour).

The ”HTML notation” is merely a representation of the values for red, green and blue in hexadecimal system. The first two digits stand for the value for red, the third and fourth digit for the value for green and the last two digits for the value of blue. This notation is commonly used to describe colours on websites, e.g. the page background.

How to make an anaglyph

If you wish, you could let your students make anaglyphs themselves as a student project. All you need is a digital camera and a computer with photo editing software.

In a first step, you would need to take one photo each from the perspective of the left and the right eye, respectively. The two camera positions should be approximately 7 cm (normal eye distance) apart, and the two camera orientations well aligned.

The following step-by-step description is based on using the ”gimp” software. Other photo editing software might offer the same features using slightly different names.

1) Open the right eye view. Then open the left eye view as a separate layer in the same picture, using the menu item “File | Open as Layers”.
2) In the window “Toolbox”, select the “Bucket fill” tool and make sure that the option “Fill whole selection” is set. As filling colour choose black.
3) Select the whole picture by choosing the menu item “Select | All”.

4) Look in the window “Layers, Channels”. You will see in this window different taps, one with the title “Layer”, which shows the two photos of the different perspectives. Click on the layer titled “Background”.
5) Go to the tap titled “Channels”. Normally, all four channels Red, Green, Blue and Alpha are selected (blue shaded). Click on the channel titled “Green”, “Blue” and “Alpha” to deselect these channels (they are now grey shaded), so that only “Red” remains active.
6) Click twice on the large photo. The small icons next to the channel title “Red” should be black now (you erased the red part of the right eye’s perspective)
7) Go back to the tap titled “Layers” and select the upper layer, namely, the left eye’s perspective. Directly under the tap’s title “Layers” you will find the menu item “Mode”. Select “Addition”. Thus, the computer performs an additive colour mixing of the two layers.
8) Go again to the “Channels” tab and deselect the “Red” and “Alpha” channels.
9) Click twice in the main picture to erase the Blue and Green channel in your left eye’s perspective.
10) Done! Look at the result with a red and cyan filter to check the 3D effect. If the effect is not as desired, most probably the alignment of the cameras was not accurate enough.

Students might ask

1) How many colours can we see?

This depends strongly on the observation conditions and differs from person to person. However, it is estimated that the human eye can distinguish around 10 million different colours.