Van Gogh in close-up

Van Gogh Museum
Amsterdam

teacher's guide for science classes

Photograph on front page: Ella Hendriks, conservator at the Van Gogh Museum, examining *The bedroom* by Vincent van Gogh. Photograph by Thomas Fasting

Contents

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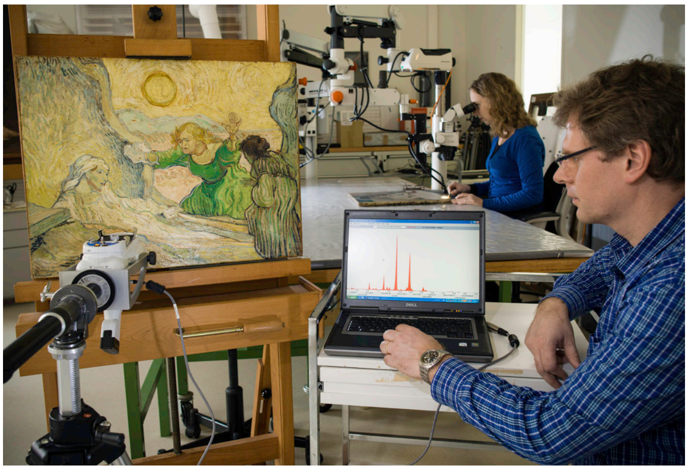
Research by the Cultural Heritage Agency using a portable XRF scanner; photo © René Gerritsen Amsterdam.



Description of the programme
This teacher's guide contains suggestions for school lessons that you could use before taking a group of students to visit the Van Gogh Museum, or simply if you like the idea of discussing assignments related to Van Gogh with your class. The lessons can also be used without visiting the museum.

The lessons in this guide are suitable for physics and technology classes in the final years of secondary school. If you are interested in suggestions for classes in arts subjects, please refer to our website, which has different teachers' guides for these subjects.

To introduce the subject, you could give a short description of the life of Vincent van Gogh. To do so, you can use the background information that can be found on the website of the Van Gogh Museum. Of course, you could also invite your students to look up general information about Van Gogh for themselves, in the library or on the internet. You will find some useful literature and websites for this purpose on page 49. If you want to visit the museum with a group of students, it is best to ensure that the students have been adequately prepared beforehand. This will greatly increase the value of the museum visit. For information about reserving a museum visit for a school group, please go to
www.vangoghmuseum.com/education

The teacher's guide is available in Dutch, English and French.

Van Gogh for science students
The lesson plans in this teacher's guide are ideally suited to science classes, whether in general science lessons or in physics, chemistry of biology class.

In the lesson series Van Gogh in close-up we deal with the technical side of Vincent van Gogh's work. Lesson 1 combines elements of biology and physics, while lessons 2 and 3 combine elements of physics and chemistry. The lessons are structured to fit into a lesson lasting between 50 and 60 minutes.

Goals of this lesson series
• Students learn about the technical background of Van Gogh's paintings.
• Students learn about research on Van Gogh's paintings and the technological aids used for this research.
• Students learn about Van Gogh's use of materials, working methods, and experiments with colour.
• Students are provided with enough information to prepare them for a visit to the Van Gogh Museum and can follow this visit up in a meaningful way.

Lesson 1
An eye for Van Gogh explains the perception of colours. It discusses the way these perceptions work in the eye and the way in which Van Gogh used these perceptions.

Lesson 2
Van Gogh and discolouration discusses the influence of environmental factors on colour. The colours we see now are not necessarily the same as those originally applied to the canvas.

Lesson 3
Invisible to the naked eye shows diverse innovative techniques allowing us to look inside Van Gogh's work.

To a large extent, the subject for which you plan a visit the museum will naturally determine the content of your preparatory and follow-up lessons. The level of your class will also be a major consideration. Based on these factors, you can attach more specific goals to your classes.

Reservations
All school visits must be reserved in advance through the online reservation system at **www.vangoghmuseum.com/education**

For information about extra activities at the museum, go to **www.vangoghmuseum.com**

An eye for Van Gogh
Lesson 1

Lesson goals
By the end of the lesson, the students will know:
- who Vincent van Gogh was, and how the use of colour plays a role in his paintings.
- how colours are perceived by the eye.
- the difference between the light colour wheel and the colour wheel for painting.
- what complementary colours are, and how Van Gogh uses them.

Materials required
- student sheets to read the text and answer sheets on which to fill in answers to certain questions.
- computer on which to show the introductory film.
- computers for the students, for question 9.
- colour pencils.

Time frame

15 min	brief introductory film, explanation by teacher.
10 min	students work on questions 1 to 4.
10 min	discussion of the contrasts and the difference between the two colour wheels.
20 min	students work on questions 5 to 11.

Suggestions for lessons and extra information

This section contains extra information about the questions in the student sheets. You can use them to provide explanations as you are going along. As the students use the assignment sheets *An eye for Van Gogh,* they will independently get to know Vincent van Gogh and a number of works from the collection of the Van Gogh Museum. Some of the questions will prompt students to go in search of more information, for instance in books or on the internet.

Introduction
What do students know about the eye and the way colours work? If you want, you may decide to show the following film, produced by the Blue Man Group, as an introduction to the subject:
https://www.youtube.com/watch?v=EwjFTcNE-WE

What do they know about Van Gogh? Discuss Van Gogh's letter about *The Zouave* with your class. This letter makes it clear that Van Gogh's use of colour was highly deliberate.

Contrast
Complementary colours in light are different from complementary colours in paint. When mixing light of different colours, we refer to 'additive' colour mixing. When we are dealing with printing and paint colours, however, colour mixes are 'subtractive'. In the additive system, a mixture of red, green and blue light produces white. In the case of paint colours, however, there is subtractive mixing: a mixture of red, yellow and blue produces grey.

Supplementary background information
http://facweb.cs.depaul.edu/sgrais/color_perception.htm

Answers

1. Check whether the student has connected the red and green lines correctly to the left and right cerebral hemispheres.

2. Right: 5x103 per 10mm2, left 140x103 per 10mm2 (macula lutea).

3. Blue: 390- 545 nm, red: 410 – 710 nm, green: 390 – 660 nm.

4.

colour	red % cone	green % cone	blue % cones
orange frame	*40*	*5*	*0*
red sky	*5*	*0*	*0*
blue figure at the fence	*8*	*14*	*80*
yellow figure at the fence	*90*	*40*	*0*

Several different cones are active in the perception of all the colours with the exception of the red sky.

5.

primary colour	the colour wheel of Charles Blanc	the light colour wheel
red	*green*	*cyan/light blue*
blue	*orange*	*yellow*
green		*magenta/bright pink*
yellow	*purple*	

6.

	mixed/secondary colour
red and blue	*purple*
blue and yellow	*green*
yellow and red	*orange*

7. The mixed/secondary colour is the complementary colour of the primary colour that is not in the mixture.

8. Green-red: water lilies, bamboo, dress.
Blue-orange: water and bamboo.

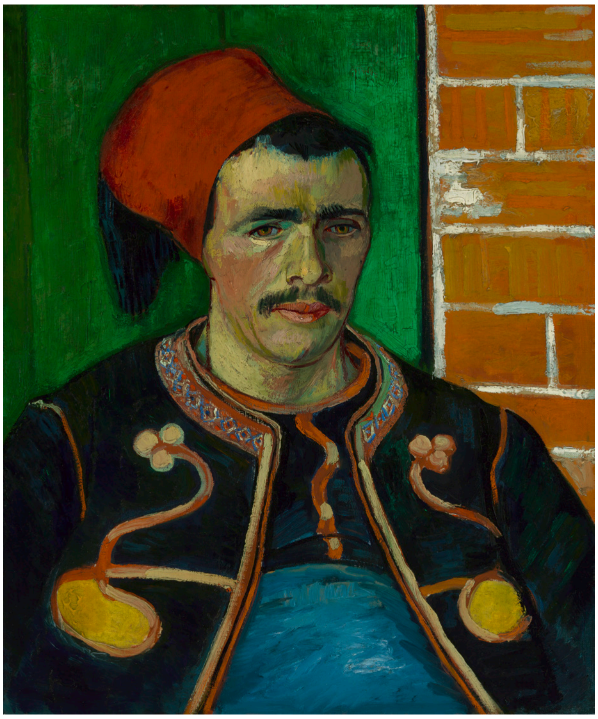
9. Examples: Crab on its back, Self-portrait as a painter, The yellow house, Sea view at Les Saintes-Maries-de-la-Mer, Butterflies and poppies.

10. E.g. by making the background or the frame purple.

11. The colours become more vivid.

An eye for Van Gogh

This lesson is the start of a scientific voyage of discovery to the works of Vincent van Gogh and the way in which he made them. The assignment sheets are about Van Gogh as an artist and as a colour researcher. As you tackle the assignments, you will look at a number of paintings with the eye of a biologist or a physicist and see the choices that Van Gogh made.



1. Vincent van Gogh, *The Zouave,* 1888,
Van Gogh Museum Amsterdam (Vincent van Gogh Foundation)

Colours are important in Van Gogh's paintings. He deliberately used certain colour combinations because of their strong contrasts. We know this, among other things, because many of the letters he wrote to his brother Theo have been preserved. Have a look at what he wrote about his painting *The Zouave* (fig. 1), a portrait he made of a soldier.

'I have a model at last — a Zouave — he's a lad with a small face, the neck of a bull, the eye of a tiger, and I started doing one portrait and started again on another. The bust-length I painted of him was terribly hard. In a uniform the blue of blue enamel saucepans, with dull orange-red trimmings and two lemon-yellow stars on his chest, a common blue and very hard to do.
I've stuck his very tanned, feline head, wearing a bright red cap, in front of a door painted green and the orange bricks of a wall. So it's a coarse combination of disparate tones that isn't easy to handle — the study I did of it seems very hard to me, and yet I'd always like to work on portraits that are vulgar, even garish like that one. It teaches me, and that's what I ask of my work above all.'

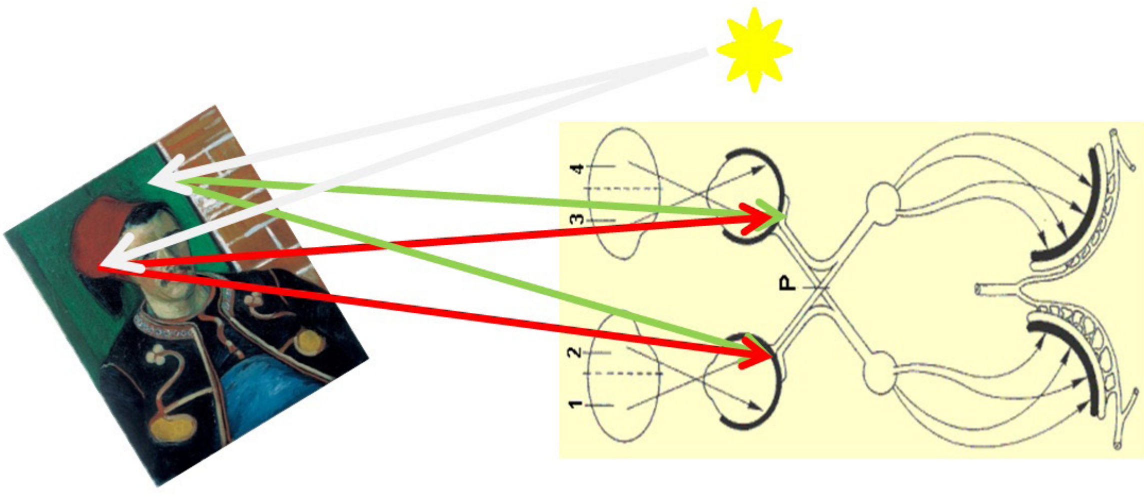
Vincent van Gogh in a letter to his brother Theo, Arles, Thursday 21 June 1888

Clearly, then, Van Gogh thought very deeply about the effects that may be produced by different colours. But how do we perceive colours? Which parts of the eye are responsible for our perceptions of colour?

An eye for colour

You can see colours because light falls upon an object. A white beam of light is a mixture of all the colours of the spectrum. Take a look at figure 2. If a beam of white light falls on the yellow hat in the self-portrait, the hat absorbs all the colours except for yellow. The yellow light is reflected back. That yellow beam of light strikes the retina in our eyes. The retina converts this yellow light energy into an electrical signal, the action potential. The signals are transported along the nerves of the retina. The nerve bundles cross in the head, ending up in the visual area of the brain, which then emits the signal that the hat is yellow.

2. Vincent van Gogh, *Self-portrait with pipe and straw hat,* 1887,
Van Gogh Museum Amsterdam (Vincent van Gogh Foundation)



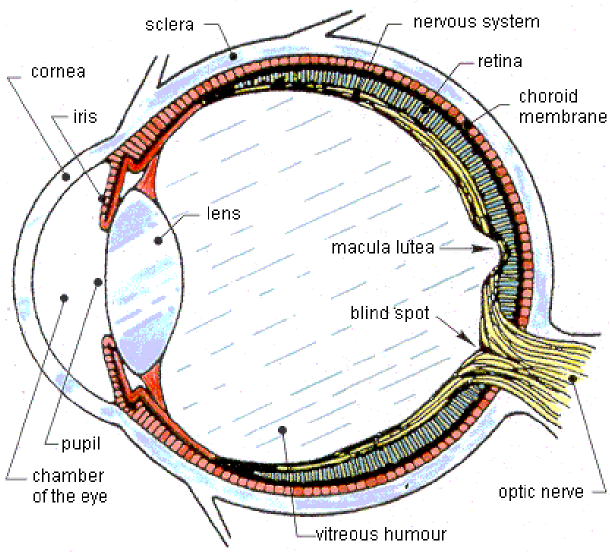
3. Assignment 1

?

1. Show how the red of the hat and the green of the background of *The Zouave* end up in your brain. On your assignment sheet, draw a red and a green light beam to each eye, and for each colour show how the 'colour information' travels to the correct hemisphere of your brain. If you want, you can use a vademecum with science data and illustrations.

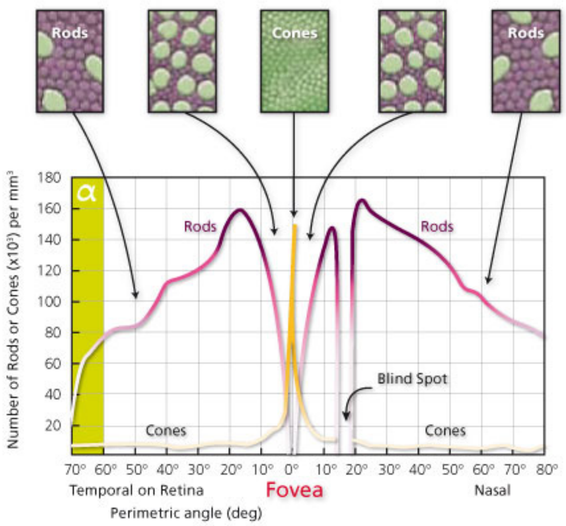
Colours and cones

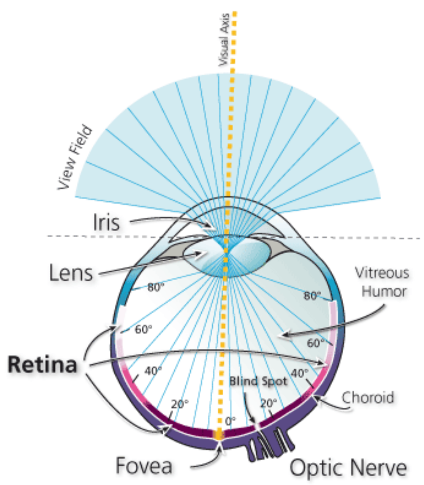
Rays of light strike the retina. The retina is the innermost layer of the eye, one end of the central nervous system. It consists of nerve cells that line the inner surface of the eyeball. The retina is made up of special cells known as rods and cones. It is these that process light. The cones are responsible for the perception of colour. It has been estimated that the human eye contains approximately five to seven million cones. The number of rods is even larger, at some 110 to 130 million. The cones are found primarily in the central region of the retina, the macula lutea ('yellow spot'), while the rods are found primarily around the outer edges of the retina.



4. Drawing of the eye. Source: *Kijken en Zien, een nlt-module voor 5 vwo*. Junior College, Utrecht.

In the graph in fig. 5 you can read off the distribution of rods and cones per mm2 on the retina. The horizontal axis gives the angle of perception. This makes it clear that your eye is most sensitive in the macula lutea. The illustrations above the graph show the distribution of rods (purple) and cones (green) in the area indicated by the arrow. The vertical axis gives the numbers.

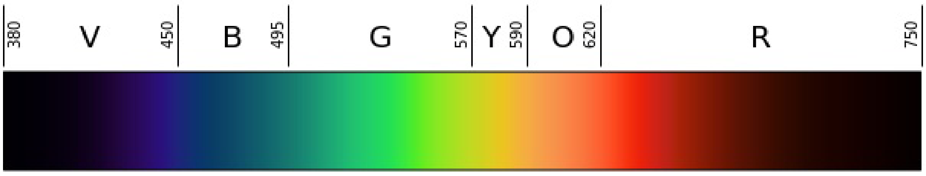




5. Graph showing the distribution of rods and cones per mm2 of the retina

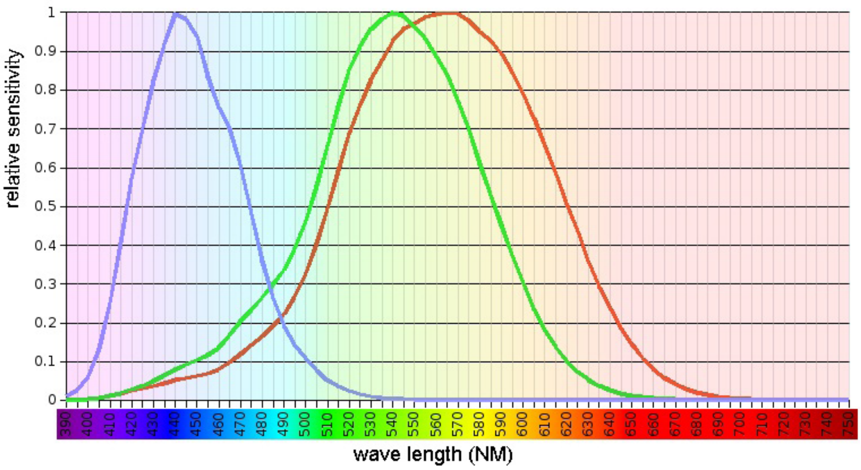
6. Drawing of the eye

The human eye can perceive colour in wavelengths ranging from 380 to 750 nm. Each cone possesses a pigment that is sensitive to light of a specific wavelength. The human eye possesses three types of cones: cones that are sensitive to blue light, those that are sensitive to red light, and those that are sensitive to green light. The blue cones are sensitive to all colours within the range of the blue wavelength, red cones to those within the range of the red wavelength, and the green ones to those within the green wavelength.



7. Linear visible spectrum. Source: wikipedia

Fig. 8 shows all the colours of the spectrum. In this graph you can see which cones are responsible for the perception of the different colours. All mixed or 'secondary' colours are perceived by different cones working together.



8. Spectral sensitivity of cones. Source: wikipedia

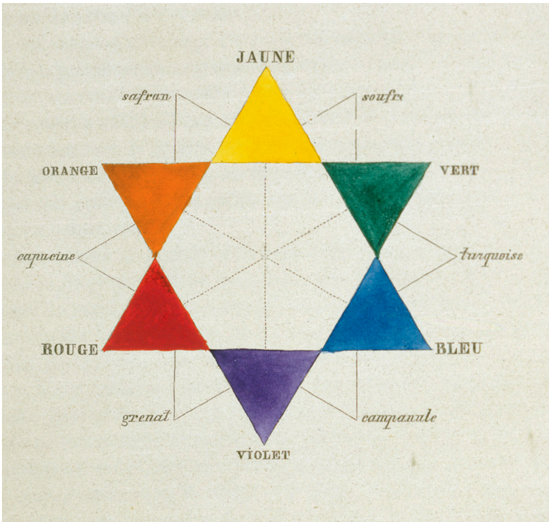
9. Vincent van Gogh, *Flowering plum orchard (after Hiroshige)*, 1887, Van Gogh Museum Amsterdam (Vincent van Gogh Foundation)

?

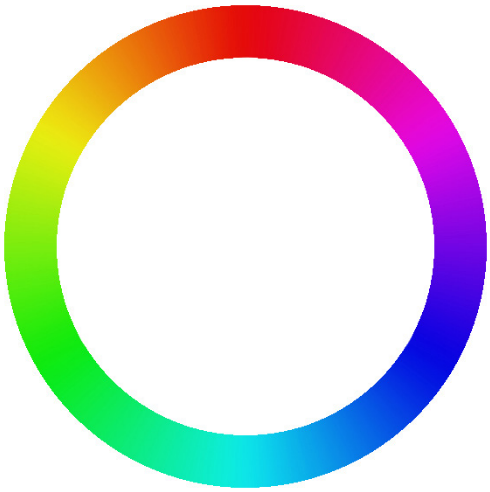
2. Look at the graph in fig. 5. How many cones do you have 20 degrees to the right of the macula lutea? And how many to the left of the macula lutea?
3. Look at the graph in fig. 8. For which wavelength is the blue cone the most photosensitive? For which wavelength is the red cone most photosensitive? And for which wavelength is the green cone most photosensitive?
4. Determine for Van Gogh's painting *Flowering plum orchard (after Hiroshige)* (fig. 9) which cones are used to perceive specific colours. Use the graph in fig. 8 and the table on your answer sheet. Look up the three colours in the table and write down which cones are active for each one. Which of the colours in the painting will require more than one type of cone to be active in their perception?

Contrast

Although the colour theory with the three cones explains a great deal about the way we perceive colours, there is another factor: complementary colours. These are colours on opposite sides of the colour wheel. The colour wheel that Van Gogh used was the one that applies to *paint.* There is another one, however; the colour wheel for light. The colour wheels are different, because the primary colours of light are different from the primary colours of paint. What is more, the colours of light mix in a different way from those of paint. Fig. 10 shows the colour wheel that Van Gogh used. He saw it in a book by Charles Blanc: *Grammaire des arts du dessin, architecture, sculpture, peinture*. Fig. 11 shows the colour wheel for light.



10. Colour wheel of Charles Blanc



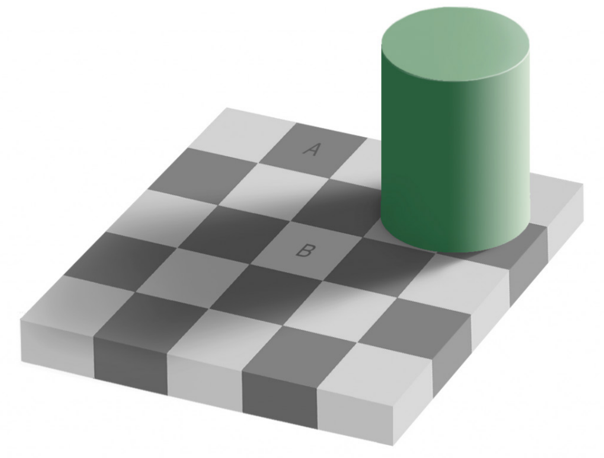
11. Colour wheel of light. Source: wikipedia

?

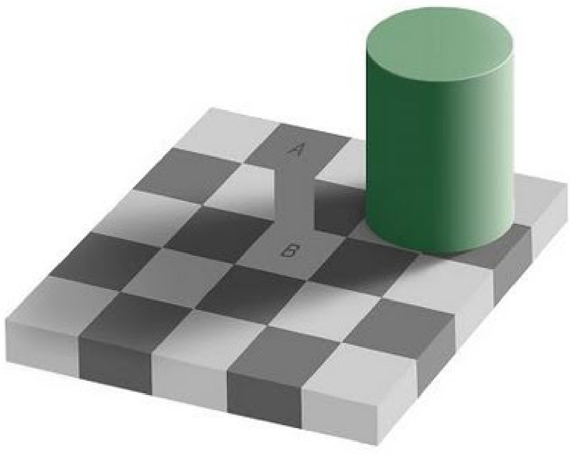
5. In the table on the answer sheet, fill in the complementary colours of the primary colours of the different colour wheels. Use figs. 10 and 11 to help you.

Simultaneous contrast

How a colour is perceived depends on the colours surrounding it. Take a look at fig. 12. The areas marked A and B are the same colour, but because of the colours surrounding them, that's hard to believe. In fig. 13 you see that they are really the same colour. This effect is known as simultaneous contrast: how you perceive a colour is influenced by the colours next to it.



12. Source: www.kennislink.nl



13. Source: www.kennislink.nl

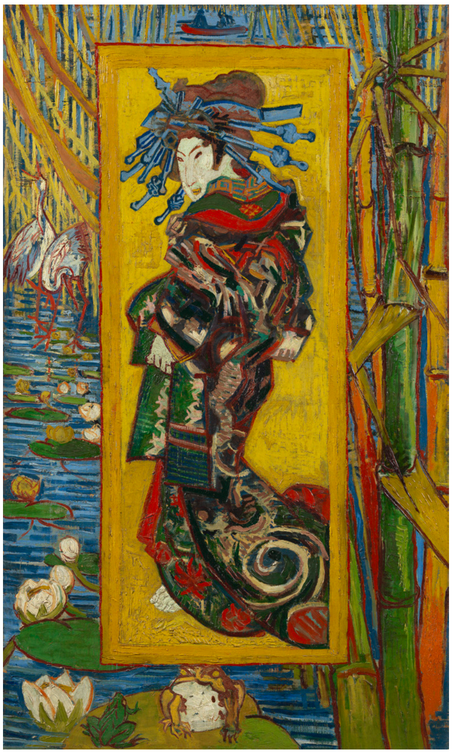
A painting is a mixture of many different colours. Vincent van Gogh often used simultaneous contrast in his paintings. He read about this effect in the book by Charles Blanc. Colours that are each other's opposites in the colour wheel, complementary colours, are especially prone to reinforce each other if they are placed side by side in a painting. Van Gogh liked to exploit this effect, since it made the colours in his paintings stronger.

?

6. What colour do you get if you mix the primary colours red, blue and yellow? Fill in the table on the answer sheet.
7. Take another look at the results of question 6. What can you say about the complementary colour of the mixed (secondary) colour?

14. Red lacquered box containing balls of wool, Vincent van Gogh Museum, Amsterdam (Vincent van Gogh Foundation)

Balls of wool
Van Gogh made use of an unusual aid when working on his colour studies: a small box with balls of wool. Some of the balls in the box were made up of threads of different colours, and others were made from different hues of a single colour. Van Gogh would place the balls beside one another, or wind threads of different colours around each other, to see the effect of different colour combinations. Some balls were evidently used for a specific painting: one ball displays precisely the same combination of yellows and ochres as *Quinces, lemons, pears and grapes* (fig. 16). The Van Gogh Museum possesses the original box with balls of wool that Van Gogh used for his work in its collection.



15. Vincent van Gogh, *Courtesan (after Eisen)*, 1887, Van Gogh Museum, Amsterdam (Vincent van Gogh Foundation)

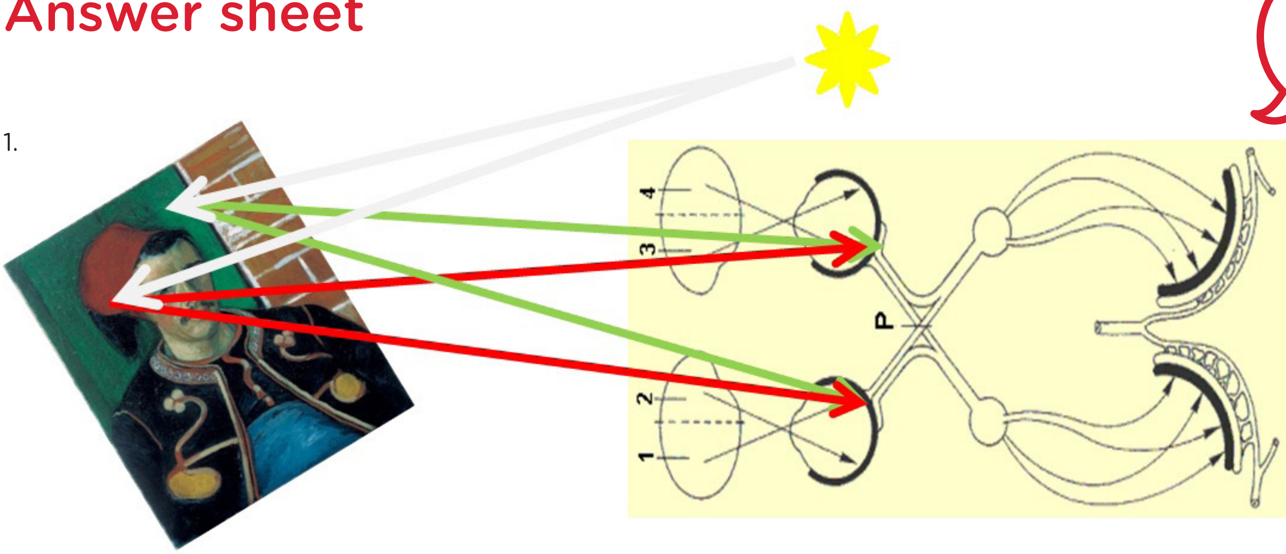
8. Take a good look at the painting *Courtesan (after Eisen)* by Van Gogh (fig. 15). Where in the painting do you see the combination of complementary colours as shown by Charles Blanc?
9. The Van Gogh Museum possesses hundreds of works by Van Gogh. Have a look at the museum's permanent collection and see if you can find at least five works in which simultaneous contrast is clearly visible.
http://www.vangoghmuseum.nl/vgm/index.jsp?page=425&lang=en

16. Vincent van Gogh, *Quinces, lemons, pears and grapes, 1887,* Van Gogh Museum, Amsterdam (Vincent van Gogh Foundation)

10. In fig. 16 you see *Quinces, lemons, pears and grapes* by Van Gogh. He has given one colour – yellow – the starring role here. Can you make a painting out of it using a complementary contrast? (To do this assignment, colour in fig. 17 on your answer sheet).
11. Describe the effect of the change in your version of the painting *Quinces, lemons, pears and grapes*, after you've added the complementary colour(s).

Answer sheet

1.



4.

colour	red % cone	green % cone	blue % cones
orange frame	40	5	0
red sky			
blue figure at the fence			
yellow figure at the fence			

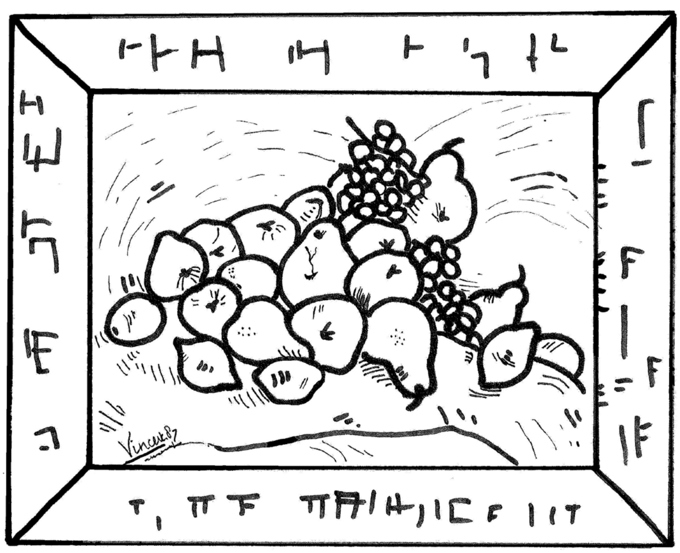
5.

primary colour	the colour wheel of Charles Blanc (fig. 10)	the light colour wheel (fig. 11)
red		
blue		
green		
yellow		

6.

	mixed/secondary colour
red and blue	
blue and yellow	
yellow and red	

10.



Van Gogh and discolouration

Lesson 2

Lesson goals

By the end of the lesson, the students will know:

- what paint consists of.
- how an object gets its colour.
- how the colours in a painting may change over time.
- the methods that can be used to try and prevent discolouration.

Materials required

- beamer and computer to show films.
- student sheets to read text and an answer sheet to fill in answers to some of the assignments.
- computer for students if assignment 13 is done in class.
- experiment 1: one blank CD or DVD for each student or pair of students.
- experiment 2: For each student: white paper (a quarter of an A4 sheet is big enough), a small piece of silver foil, adhesive tape, eosin solution, methylene blue solution, a brush and a large window (make sure that the solutions are brightly coloured: 1 g for every 100 ml of water).

Time frame

10 min	explanation by the teacher about colour, paint, and discolouration.
10 min	students carry out experiment 1 and answer assignments 1 and 2.
5 min	explanation by the teacher about paint. Assignment 4 can be incorporated into the explanation or set as homework.
21 min	students do assignments 3 to 8 and carry out experiment 2.
5 min	the teacher explains a little about the restoration of *The bedroom.*
2 min	show the film: **http://www.youtube.com/watch?feature=player_embedded&v=GpIH2mnXeuQ**
2 min	students answer assignments 9 to 11.

Lesson suggestions and additional information

This section provides additional information about the assignments in the student sheets. You can use them for giving explanations as you go along.

Van Gogh and discolouration
This part discusses a lot of theory relating to molecules and atoms. It contains two experiments that help to corroborate the theory. It would be useful for you to carry out the experiments yourself beforehand.
The object of the first experiment is to display the spectrum.

Pigment particles consist of molecules. A molecule is the smallest particle of a substance that contains that substance's chemical properties. Each molecule is made up of atoms. An atom consists of a nucleus, around which electrons spin in circular orbits (imaginary shells). Each atom has several of these 'shells', containing different numbers of electrons. For chemical bonds, the electrons in the outermost shell are the most important. These electrons are involved in forming and breaking chemical bonds between atoms.
When light strikes a pigment particle, energy can be transmitted to the atoms. Only if this energy corresponds precisely (in terms of wavelength) to the energy needed to raise the electrons to a higher energy level, will the energy of this radiation be absorbed. In that case, the energy can be converted into the movement of the atoms. This raises the temperature of the substance. The remaining light that strikes the pigment particle (that is, light of other wavelengths) is reflected. The colour we see is the part of the light that is not absorbed, but reflected.

What is paint composed of, and under what conditions can the colour of paint change over time?
The teacher explains: A pigment is not the same thing as a dye. A pigment is insoluble, while a dye is soluble. Dyes attach themselves to the object to be coloured. Pigments don't; they have to be attached by using a binding agent. You can make a dye into a pigment by precipitating it on a substrate, usually alum. This type of pigment is known as a lake. Van Gogh often used the paint geranium lake, produced by precipitating eosin on alum.

Assignment 4 calls for the students to do some research on the internet. That takes time. You may choose to skip this assignment, or set it as homework.

You can discuss the following examples of discolouration with the students, and then have them tackle the relevant assignments and experiment. Experiment 2 is a short experiment that demonstrates discolouration. The results take a week to appear, since the sunlight must be left to do its work.
The influence of light and oxygen: In a 'non-lightfast' pigment, the energy absorbed from the light alters the molecular structure of the pigment, generally splitting it into two or more smaller parts. As a result, the colour fades. In some cases the colour vanishes altogether. That is what happens when geranium lake fades, for instance.
Yellowing of the upper layer of varnish: See the explanation on the student sheet. A chromophore is a group of atoms in a molecule that absorbs light and in this way gives the pigment its colour. These parts of a substance have strong absorption at the blue end of the spectrum.

The colours of *The bedroom*
The teacher explains (after assignment 8): The colours that Van Gogh described in his letter no longer correspond precisely to those we see in the painting today. You can find the entire letter at: **http://www.vangoghletters.org/vg/letters/let705/letter.html**
We have already seen that geranium lake (eosin) faded under the influence of light. Van Gogh produced the colour violet by mixing blue and red. Research on a paint sample taken from the painting reveals that some of the red pigments consist of geranium lake (eosin) and cochineal. Van Gogh also used this geranium lake in the door. In the course of restoration work carried out in 2010, every square millimetre of the painting was tackled.
Old retouches and discoloured layers of varnish were removed carefully, using a solvent. Areas without paint were restored carefully by filling them up to the appropriate level and retouching them. The retouches consist of stable pigments, relatively insensitive to light, mixed with a binding agent that remains easily soluble. This means that they can easily be removed in the future. This process is shown clearly in the following short film: **http://www.youtube.com/watch?feature=player_embedded&v=GpIH2mnXeuQ.**

You can find more information here:
http://www.vangoghmuseum.nl/blog/slaapkamergeheimen?lang=en

Answers

Questions accompanying experiment 1:
Violet, blue, cyan, green, yellow, orange and red.
Yes.

Questions accompanying experiment 2:
The difference between the covered part and the exposed part.
The ink fades.
Otherwise you would not have any material for the purpose of comparison.

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1. More energy. The wavelength of UV light ranges from 10 to 400 nm. The wavelength of infrared light ranges from 750 nm to 1 micrometer. The longer the wavelength, the less energy is contained in the radiation. So UV light contains more energy.

2. A white surface reflects all radiation. That helps to keep the houses cool.

3. A dye dissolves and attaches itself to the object to be coloured. A pigment is insoluble and needs a binding agent in order to become attached to a surface.

4. More than one answer is possible. The molecular formula is given in parentheses. Organic pigments: madder lake ($C_{14}H_8O_4$), cochineal ($C_{22}H_{20}O_{13}$), indigo ($C_{16}H_{10}N_2O_2$), geranium lake ($C_{20}H_6Br_4Na_2O_5$). Inorganic pigments: cobalt blue ($CoO \cdot Al_2O_3$), chrome yellow ($PbCrO_4 \cdot PbSO_4$), white lead ($2PbCO_3 \cdot Pb(OH)_2$, zinc white (ZnO), vermilion (HgS), yellow ochre ($Fe_2O_3 \cdot H_2O$), yellow arsenic (As_2O_3). The difference between organic and inorganic pigments is that organic pigments are carbon compounds, while inorganic pigments are metal compounds.

5. To give paint its colour.

6. No, the paint acquires a green sheen because the transparent, yellowed layer of varnish mixes in the eye with the blue.

7.

letter	**colour fig. 6**	**colour fig. 7**
walls pale violet	light blue	violet
red floor tiles	dull, faded red	red
bed and chairs fresh butter yellow	yellow	yellow
sheet and pillows very bright lemon green	greenish	greenish
bedspread scarlet red	dark red	red
window green	green	green
dressing table orange	orange	orange
basin blue	blue	blue
doors lilac	blue	lilac

The red floor has faded, the violet walls have turned light blue and the lilac door has turned blue. The cause is Van Gogh's use of red geranium lake (floor) and cochineal (door and walls).

8. Red (the walls, the floor tiles, the doors). The geranium lake (eosin) has faded under the influence of light.

9. Keep the level of light (measured in lux) low. Make sure that the air is free of impurities. Place a pane of glass in front of the painting to keep off grime. Use lighting that is free of UV radiation. Use a good climate control system.

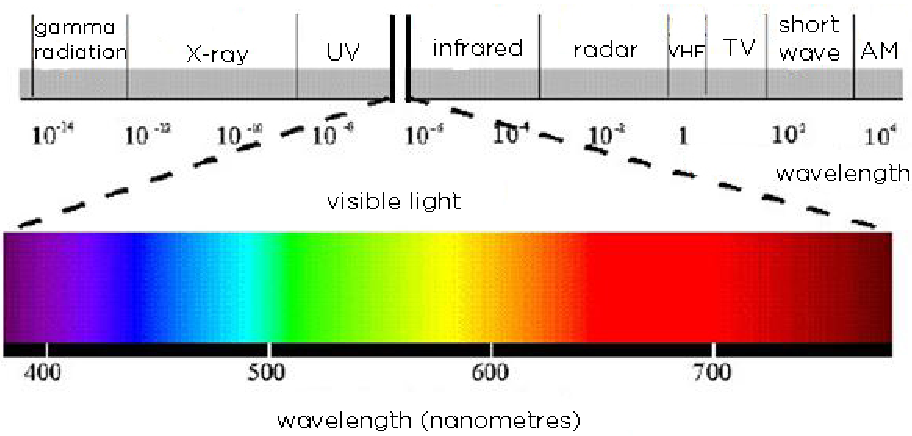
10. The old layers of varnish have been removed.

11. It filters the light. It helps (together with the protective back) to create a constant microclimate. It keeps dirt away from the painting. The painting cannot be touched.

Van Gogh and discolouration

The paintings hanging in a museum do not necessarily look the way they looked when they were first painted. Some of them have become discoloured, as a result of external conditions or processes in the paint. In this lesson we shall take a closer look at the discolouration of Vincent van Gogh's paintings. We need to start by explaining a little more about what it is that determines an object's colour, the composition of paint, and what can cause it to become discoloured.

What determines the colour of an object?
Colour is visible because part of the light that strikes a coloured object is scattered to the eye. To understand how that works, you need to know a few of the physical properties of light. Light consists of electromagnetic rays. Only a small part of the electromagnetic spectrum is visible to us. For instance, we can't see ultraviolet (UV) or infrared radiation (fig.1). UV radiation is what causes us to get a tan, and infrared radiation provides heat.



1. The electromagnetic spectrum

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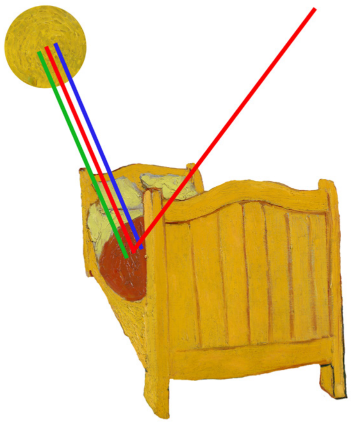
1. Does UV radiation contain more or less energy than infrared radiation? Explain.

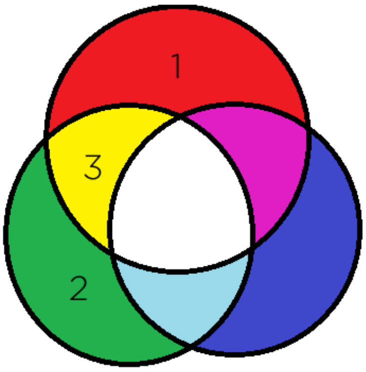
Experiment 1.
Take a new CD or DVD and hold it in the sunlight at a slight angle. You will see a whole range of colours. That is called the spectrum of visible light. This shows you that white sunlight consists of many different colours.

What colours do you see?
Do these colours correspond to the colours in fig. 1?

What causes colour?
Colour is caused by the interaction of visible light with the electrons of the substance on which the light shines. If all the radiation of the light is absorbed, we see that object as black. If all the radiation is scattered, we see the object as white. The part of the light that is scattered is seen as colour. The rest is absorbed (fig. 2).



2. Absorption and reflection of light.



3. Mixing with light.

Example
If a substance only absorbs the blue light (400 nm-490 nm) from the total spectrum (white light), light with wavelengths ranging from 500 nm to 700 nm from the spectrum is scattered. These wavelengths correspond to green (2) and red (1) light, respectively. When our eye perceives green and red light simultaneously, we see it as yellow (3) (fig.3).

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2. Why are houses in hot countries often painted white?

What does paint consist of?
Paint usually consists of three primary components:

Pigment is responsible for the covering power of the colour of a paint layer. Pigments are small, solid, insoluble particles. They can be divided into organic pigments (deriving from plants and animals) and inorganic pigments (deriving from minerals and earth).
The binding agent ensures that the grains of the pigment adhere to each other and to the ground. It determines the properties of the paint layer, such as attachment, lustre, and durability. Linseed oil is frequently used for this purpose.
A solvent is added to dilute the paint a little to make it easier to work with. The solvent evaporates during the drying process.

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3. What is the difference between a dye and a pigment?
4. Search on the internet for the names of two inorganic and two organic pigments. Give the molecular formulas of these four pigments. What is the main difference between the organic and the inorganic pigments? (Look closely at their molecular structure.)
5. What do you use pigments for?

What can cause the colour of paint to change over time?

The influence of light and oxygen
Many pigments can fade and/or lose their colour under the influence of light and oxygen. Yellow, for instance, may become darker.

Yellowing of the uppermost layer of varnish
The best-known ageing effect is the yellowing of the top layer of varnish. This is clearly visible in fig. 4: the edge of the painting The bedroom during its restoration. When a small piece of varnish is removed, you see the bright colour of the paint beneath the discoloured varnish. Varnish consists of resin, dissolved in solvents. The molecules in the resin react with O2 from the air (oxidation). This reaction yields a product that contains a chromophore (a group containing colour). It is this that causes the yellowing of the varnish.

4 The edge of *The bedroom*, from which a small piece of varnish has been removed on the right.

Soot and dust particles
In de omgeving van een schilderij zweven verschillende materialen, die zich op het schilderij kunnen afzetten. Roetdeeltjes richten bijvoorbeeld schade aan doordat ze zuur zijn en door de vernis of verflaag heen kunnen vreten. Een laagje stof is een uitstekende basis voor het vormen van microorganismen zoals schimmel – die weer invloed op de kleur kan hebben.

Sulphurous substances
Some pigments react with other constituents in the paint. Lead-containing pigments, for instance, may become discoloured because of a chemical reaction with sulphurous substances. Oil in paint in principle provides protection against this, which is why such discolouration is more likely to occur in watercolours.

Binding agent
As the paint dries, the process of chemical change begins. This is caused by the reaction of the binding agent that has been used (which contains unsaturated fatty acids) with the O2 in the air. This yields a reaction product that contains a colour. It is this that causes the top layer to turn yellow. This happens relatively soon in the case of white paint. For this reason, poppy-seed oil was often used to make white paint: this does not go yellow as severely as linseed oil, for instance, but it dries more slowly.

The ground
The ground is an initial layer, mixed with glue, which prevents the paint from soaking into the canvas. In addition, a ground makes the canvas smooth and ensures that the paint layers will become firmly attached to the canvas. The ground also has an important visual function: its colour has a direct impact on the subsequent layers of paint and therefore on the image. For instance, a white ground reflects light very strongly, which may accelerate the discolouration of the paint.

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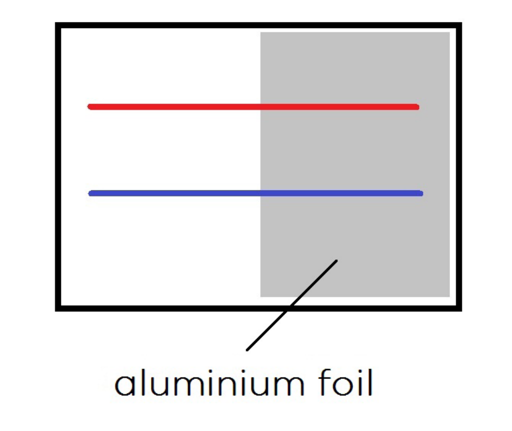
6. A blue paint is covered by a layer of varnish. This varnish starts to go yellow. Do you still see the same colour? Explain your answer.



5. Example

You need the following items: white paper, eosin solution, methylene blue solution, a small piece of silver foil, adhesive tape, and a brush.
Using the brush, paint a stripe of eosin and a stripe of methylene blue on the paper. Paste a piece of silver paper over half of each of these stripes. Make sure that these halves are extremely well covered, and that no light can get to them. Then paste the sheet of paper to the inside of the window with the stripes facing outwards, so that the sun can shine on them. Take them down after a week, and carefully remove the silver foil.

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What do you think you will see in a week's time?
Explain why you think it will look like that..
What is the point of pasting silver foil over one half and not over the other half?

The colours of *The bedroom*

Van Gogh made his painting *The bedroom* (fig. 6) in Arles, in the south of France. He sent his brother Theo a letter about the painting:

'This time it's simply my bedroom, but the colour has to do the job here, and through its being simplified by giving a grander style to things, to be suggestive here of rest or of sleep in general. In short, looking at the painting should rest the mind, or rather, the imagination.
The walls are of a pale violet. The floor — is of red tiles.
The bedstead and the chairs are fresh butter yellow.
The sheet and the pillows very bright lemon green.
The bedspread scarlet red.
The window green.
The dressing table orange, the basin blue.
The doors lilac.'

Vincent van Gogh to Theo, Arles, 16 October 1888

The colours that Van Gogh described in his letter no longer correspond exactly to those in the painting as it appears today. This is the result of discolouration. Van Gogh painted little sets of *complementary* colours side by side. These colour combinations gave this painting its vivid effect: red beside green, yellow beside purple, blue beside orange. Thanks to Van Gogh's own description of the colours, combined with what we now know about his pigments and their ageing and discolouration, researchers have produced a digital reconstruction of the original colours (fig.7). This is an approximation of what the painting may once have looked like.

6. Vincent van Gogh, *The bedroom,* 1888, Van Gogh Museum, Amsterdam (Vincent van Gogh Foundation)

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7. Look closely at figs. 6 and 7. Fill in the table on the answer sheet. The first column gives the colours as Van Gogh described them in his letter to his brother. What colours do you see in the illustrations?
8. Which of the three differences strikes you most? Which colour has caused this difference?

7. Digital colour reconstruction of *The bedroom,* made in collaboration with Roy S. Berns, Munsell Color Science Laboratory, Rochester Institute of Technology, NY, United States.

Restoration of *The bedroom*

After the restoration of *The bedroom*, the painting was given a special frame: a case with its own micro-climate and glass that repels UV light. A short film shows how the restoration of The bedroom took place. Watch this film at:
http://www.youtube.com/watch?feature=player_embedded&v=GpIH2mnXeuQ

?

9. What could you do to prevent *The bedroom* from suffering any more discolouration?
10. What kind of restoration do you see in the short film about the restoration?
11. Give three reasons for the decision to use glass that repels UV light.

Do you want to know more about the research on the paintings and the paintings themselves? Come and visit the Van Gogh Museum!

Answer sheet

7.

letter	colour fig. 6	colour fig. 7
walls pale violet		
red floor tiles		
bed and chairs fresh butter yellow		
sheet and pillows very bright lemon green		
bedspread scarlet red		
window green		
dressing table orange		
basin blue		
doors lilac		

Invisible to the naked eye
Lesson 3

Lesson goals
By the end of the lesson, students will know:
- the kind of scientific research that is conducted on Vincent van Gogh's paintings.
- the techniques that are used to study paintings and how they work.
- how research contributes to our knowledge of Van Gogh.

Materials required
- a beamer and a computer on which to show short films.
- student sheets to read the text and an answer sheet on which to fill in answers to certain assignments.

Time frame:

10 min	introduction: tell the students about research on paintings. Make it clear to them that this involves a lot of physics and chemistry.
20 min	students do assignments 1 to11.
10 min	teacher explains X-rays and the electromagnetic spectrum.
20 min	students do assignments 12 to 22.

Lesson suggestions and additional information

Research techniques
Teacher explains After the students have finished answering assignments 1 to 11, discuss the two techniques and the differences between them. Show them a drawing of an X-ray tube with its anode and cathode to explain how X-rays work. Students have seen how an underpainting can be made visible in an X-ray image, and how an underdrawing made with a pencil or charcoal can be made visible in an infrared reflectogram. X-rays don't have any colour. Even so, they do tell us about colour indirectly. Heavy elements absorb more radiation, so the X-ray will be lighter in those places. Paint consists of pigments, which are composed of elements. If you know which paint colour consists of heavy elements and which of lighter ones, this will help you to form an idea of what pigments may have been used.

Answers

1.

layer	type of layer
1	*canvas*
2	*first layer of ground*
3	*first painting*
4	*scraped-off first painting*
5	*new covering layer*
6	*second layer of ground*
7	*uppermost painting*

2. There is another painting underneath it.

3. Students can write all sorts of things here. The object is to stimulate them and get them to broaden their thinking.

4. X-rays.

5. 5. X-ray 1: bones of a hand with two rings on the ring finger. X-ray 2: human hip with three screws inserted to repair it.

6.

X-ray: light	**X-ray: dark**
heavy / light element	heavy / light element
high / low mass number	high / low mass number

7. Circles, dots, shapes that look like leaves, nails, a different image.

8. A bunch of flowers.

9. You can see a face.

10. The underdrawing that Van Gogh made with charcoal or a pencil, layer 6 in the reconstruction.

11. That for this painting he started by making a drawing of the design.

12. 1st picture: neutral atom. 2nd picture: the red arrow is the X-ray that knocks an electron out of the innermost 'shell'. 3rd picture: the gap is filled by an electron from the outermost 'shell'. This releases X-rays, which is characteristic of the element.

13. Fe, Pb, Cu, As, K, Hg, Ca.

14. Prussian blue, vermilion, Schweinfurt green, white lead.

15. The right place is the bottom of the green boat. You can count a different answer as correct if it is well argued.

16. You focus a bundle of electrons very precisely on a grain of the pigment in the paint sample. An electron is knocked out of the innermost shell. The gap in the first shell is filled by another electron from a different shell. This causes X-rays to be released. This radiation is measured. By measuring the quantity of radiation that is received, we can determine which elements are present in the paint sample.

17.

	XRF	SEM-EDX
similarity in effect	*X-rays are released*	*X-rays are released*
difference in effect	*irradiation with X-rays*	*irradiation with electrons*
advantage of use	*can be used to study a large surface area, portable (no transport needed)*	*can be used to irradiate a grain of a pigment with great precision*
disadvantage of use	*you have to penetrate through several layers of the painting*	*you need a fragment of the painting. Calls for expensive equipment.*

18. Four different layers: first two dark layers, then a light layer, and finally a very thin red layer. The layers are either very thick or very thin.

19. Colours: green, orange, yellow, white, red.

20. The ground is the white layer in the paint sample; over it is a thin top layer. So Van Gogh first painted a very thick layer and then a very thin one.

21.

layer	kind of layer	research technique
1	*canvas*	*with the naked eye (from the back)*
2	*first layer of ground*	*XRF and SEM-EDX*
3	*first painting*	*X-ray*
4	*scraped-off first painting*	X-ray
5	*new covering layer*	*XRF and SEM-EDX*
6	*second layer of ground + pencil*	*infrared and XRF*
7	*uppermost painting*	*with the naked eye*

Invisible to the naked eye

How did Vincent van Gogh work? The Van Gogh Museum has tried to answer this question by carrying out research on the letters and paintings of Van Gogh. Scientists and scholars from a range of different fields have been involved in this work. One of the results of this research is shown in fig. 1: a reconstruction of the layers beneath the painting *View from Theo's apartment* (fig.2).

1. Reconstruction of the low building in *View from Theo's apartment,* made by Kristel Smits and financed by the Australia Council for the Arts, the Australian Government's arts funding and advisory body.

2. Vincent van Gogh, *View from Theo's apartment,* 1887, Van Gogh Museum Amsterdam

In the reconstruction you can see how the original painting is built up. The central question in this lesson is: How was the Van Gogh Museum able to make this reconstruction? To answer this question, you will be looking primarily at the analytical techniques that were used in this research.

3. The different layers of a painting.

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1. A painting is made up of different layers. There are always at least two: the canvas and the paint. Frequently a painting has a ground under the paint, and a layer of varnish to protect the paint (fig. 3). Can you figure out what the other layers of the reconstruction in fig. 1 might be? Write the list down on the answer sheet.
2. The painting was evidently built up in successive stages. Can you explain how it happened that there are so many layers beneath this painting?
3. How was the Van Gogh Museum able to make the reconstruction in fig. 1? How do the researchers know that the painting consists of these layers? List as many ways as you can think of in which you might examine a painting. Also, write down what these methods will tell you about the painting. In making this list, don't forget to include the various techniques you've learnt about in classes such as biology, physics, and chemistry.

Research techniques

It's impossible to look through a painting with the naked eye. To do so, you need research techniques with which you can study the different paint layers. These techniques are not used solely for studying paintings; in fact many of them were developed for medical purposes. Here is a list of techniques that are used to examine paintings. You will be learning about some of them in this lesson.

-You can study a painting under a microscope (enlargement 400x).
-You can study the painting under raking light (light from the side) and light shining through from the back.
-You can photograph the painting with different spectra: e.g. infrared and UV rays.
-You can take paint samples and examine them closely.
-You can scan the painting (or paint samples) with XRF or SEM-EDX.

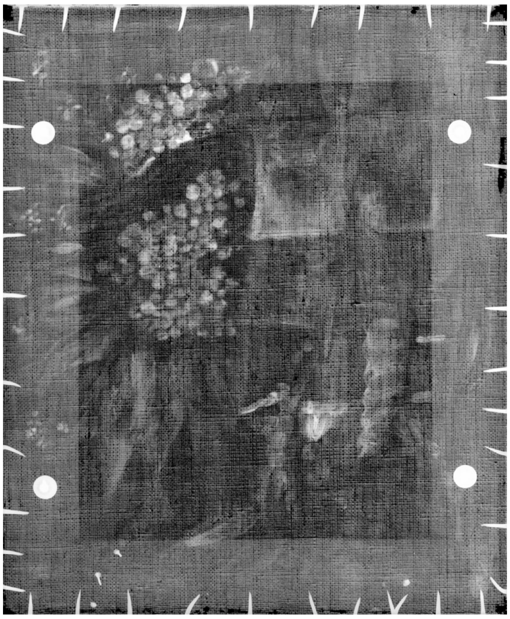
4.

5.

?

4. What technique, which is frequently used by hospitals and dentists, is also extremely useful for looking through a painting?
5. What do you see in figs. 4 and 5? Look closely at the details. Describe what you see in each of the images.
6. The light and dark patches in an X-ray tell you something about the kind of element you're looking at. X-rays can be absorbed, depending on the kind of element in that place. In the table on the answer sheet, circle the kind of element that is absorbed by the X-rays.

If you can look through the skin and tissues of a human body using X-rays, you can naturally look through a painting too. Fig. 6 is an X-ray image of one of Van Gogh's paintings:



6. X-ray image of *Nude girl, seated*

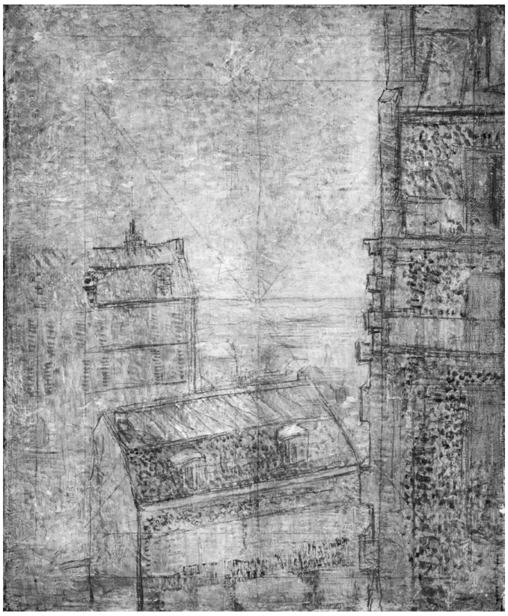
7. Vincent van Gogh, *Nude girl, seated,* 1886, Van Gogh Museum, Amsterdam (Vincent van Gogh Foundation)

7. Which sections of fig. 6 tell us something about how the painting was built up?
8. As you see, not all the areas of the surface actually go with the girl; there is another painting underneath. What did that painting look like? What do you think it represents?
9. Look closely at the X-ray of *View from Theo's apartment* (fig. 8). What kind of scene lies beneath this painting?

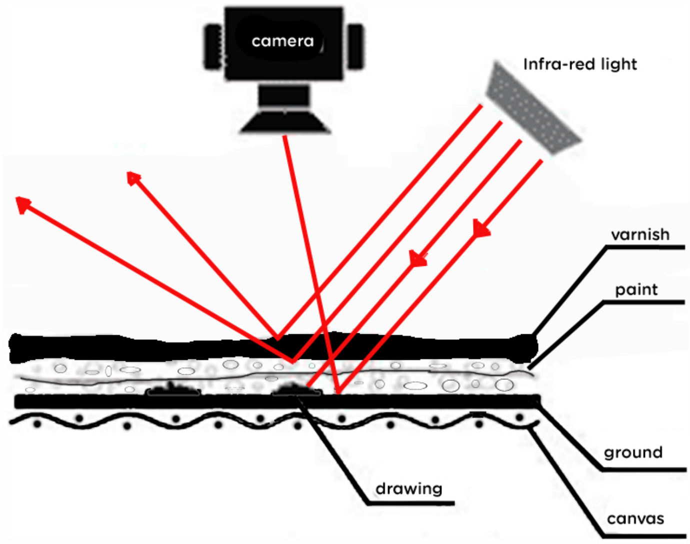
8. X-ray image of *View from Theo's apartment*

Infrared reflectogram
If you can look through a painting using X-rays, you can do the same thing using other kinds of radiation. As you know, the electromagnetic spectrum consists of different types of radiation. In the next few assignments, you will be looking at what happens in the case of irradiation with infrared light. Infrared light, which is invisible to the human eye, is strongly absorbed in paintings by carbon. If an artist has begun his painting by making a sketch in charcoal or pencil, you can get a very good picture of this first sketch by looking at an infrared photograph.

Fig. 10 shows you how infrared light is absorbed and reflected when it strikes a painting. Part of the infrared radiation goes straight through the paint and is reflected by the light ground layer. Only the part of the painting that consists of carbon absorbs the infrared radiation and is made visible in the photograph.
In fig. 9 you can see the initial sketch for the painting *View from Theo's apartment.* You can also see the lines that Van Gogh used as drawing aids. To get the perspective right in his painting, he looked through a perspective frame – a wooden frame with wires stretched taut across it. He transferred the lines of these wires to his canvas. This enabled him to capture the correct proportions of the view he was depicting.



9. Infrared reflectogram of *View from Theo's apartment*



10. Schematic diagram of the way infrared reflectography works.

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10. Which layer of the painting has this technique exposed? Take another look at fig. 1.
11. What does this teach you about Van Gogh's working methods?

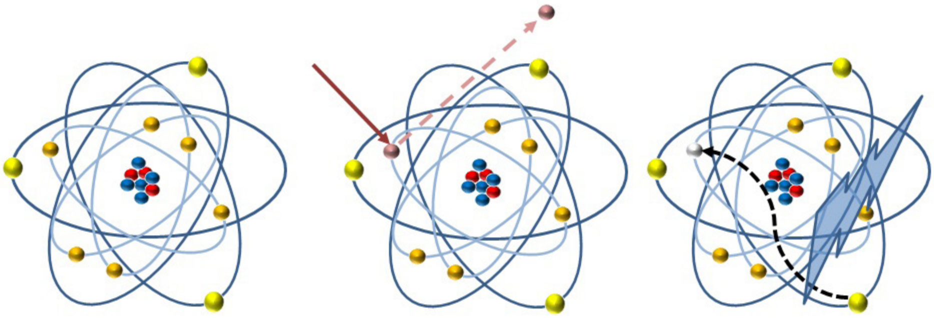
Scanning techniques

The following two scanning techniques are frequently used to examine paintings:
- *X-ray fluorescence spectrometry (XRF)*
- *Scanning Electron Microscopy – Energy Dispersive analysis of X-radiation (SEM-EDX)*

XRF: *X-ray fluorescence spectrometry*
X-ray fluorescence spectrometry (XRF) is used to establish which chemical elements are present in a sample or object. When irradiated by XRF, every element emits light in characteristic wavelengths. This makes it possible, when irradiating a painting, to identify and analyse the elements in several paint layers at once. On the basis of the elements that are present and the colour of the spot being analysed, it can then be hypothesised or established which pigments are present in the paint layers.
The painting is bombarded with high-energy X-rays. These have the effect of knocking an electron out of a low energy shell in the element (the element becomes ionised). An electron from a higher energy shell fills this gap. This releases energy in the form of low-energy X-rays. The wavelengths of the X-rays that are released in this way are specific to each element and can be made visible as peaks in a graph. This makes it possible to identify the different elements.

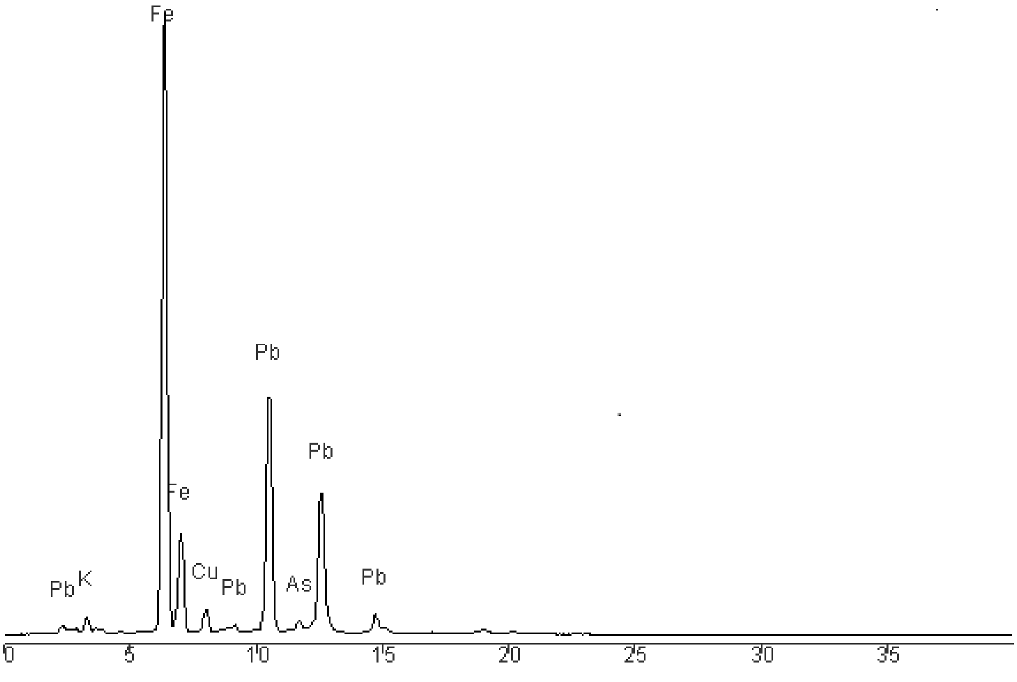
The Cultural Heritage Agency (RCE) possesses a portable XRF instrument. This means that a valuable object such as a Van Gogh painting does not need to be transported somewhere for the procedure; the researcher goes to the object. What's more, the apparatus leaves the object that is being inspected completely intact; there is no need to remove a sample.

XRF has the following characteristics:
- It penetrates different paint layers.
- It scans a surface of several millimetres.
- It scarcely causes any radiation damage, since XRF is low-energy radiation.



11. Schematic diagram showing how XRF works.

12. Explain in your own words how XRF works by writing on the pictures of fig. 11 on the answer sheet.



12. Results of XRF research on *Fishing Boats on the Beach at Saintes-Maries-de-la-Mer*

13. Vincent van Gogh, *Fishing Boats on the Beach at Saintes-Maries-de-la-Mer,* 1888, Van Gogh Museum Amsterdam (Vincent van Gogh Foundation)

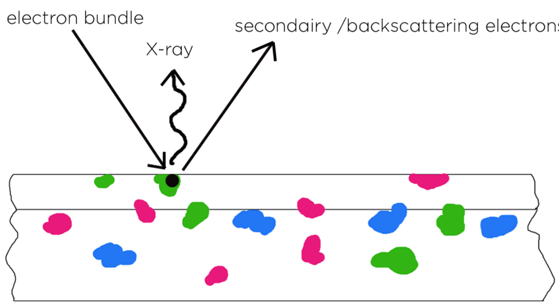
pigment	chemical formula	colour
White lead	$2PbCO_3{\cdot}Pb(OH)_2$	
Cobalt blue	$CoO \cdot Al_2O_3$	
Naples yellow	$Pb(SbO_3)_2$	
Prussian blue	$Fe(CN)_6$	
Chrome yellow	$PbCrO_4$	
Schweinfurt green	$Cu(CH_3COO)_2 \cdot 3\ Cu(AsO_2)_2$	
Vermilion	HgS	

14. Table with examples of pigments and their chemical formulas and colours.

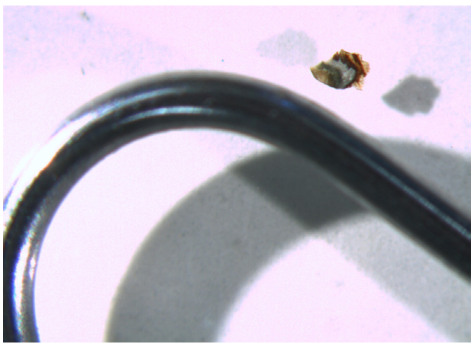
?

13. Which elements do you see represented in the graphs in fig. 12?
14. Now that you know which chemical elements are present in the painting, you can find out which pigments were probably used, and therefore what colour was used. To do this, use the table in fig. 14. What kind of pigment could this be?
15. Which area of the painting do you think this XRF scan comes from? Explain how you reached this conclusion.

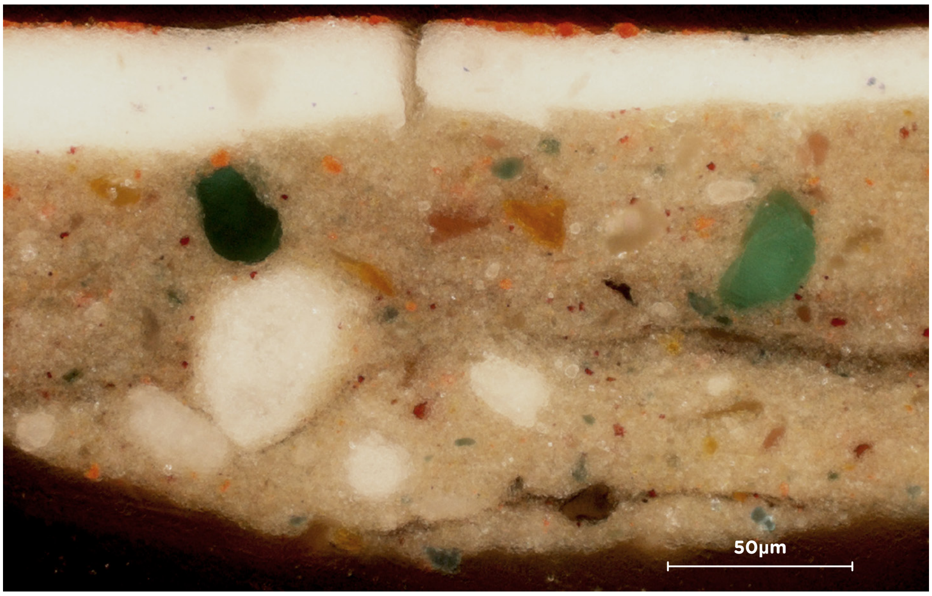
SEM-EDX: Scanning Electron Microscopy – Energy Dispersive analysis of X-radiation. (SEM-EDX) SEM-EDX,like XRF, can be used to identify the elements that are present in a small piece of the painting. A scanning electron microscope irradiates a predetermined section of a paint sample with a very narrow bundle of high-energy electrons. Just as in the case of XRF, the electron bundle causes X-rays to be released in each element. But since in this case the irradiation is done with electrons, specific particles of the paint sample can be targeted with far greater precision. Every chemical element reacts to the electrons in the bundle by emitting a different quantity of X-rays. When this is recorded in a ‘spectrum’, the peaks indicate which elements are present in the paint sample.



15. Schematic diagram showing how SEM-EDX works.



16. The paint sample used for such research is extremely small. Look at its size in comparison to a paperclip. But however tiny it may be, it can convey a wealth of information.



17. Paint sample from *View from Theo's apartment*

18. The area from which the paint sample was taken from *View from Theo's apartment.*

In fig. 17, you see a paint sample from *View from Theo's apartment.* The paint sample is a cross-section of a tiny fragment of the painting. The bottom of the sample is next to the canvas, and the top is the layer that you see when looking at the painting. The paint sample was taken at a spot where the paint had already been damaged (fig. 18). Every grain you see is a fragment of a pigment. The variation in the grains show that there is a mixture of different pigments. The colour and shape of the grains in themselves convey information that can help us identify the pigments that may have been used.

The pieces of research described above have given the Van Gogh Museum a great deal of knowledge about Van Gogh's working methods. By carrying out research on the layers in a painting, for instance, we now know that he sometimes painted over his canvases several times. The research also taught us how he produced the initial designs for his paintings, the drawing aids he used, and the colours and types of paint he used in the course of his career.

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16. Explain in your own words how SEM-EDX works.
17. You have now studied two techniques. Take the table in the answer sheet, and fill in the similarities and differences between XRF and SEM-EDX, and the advantages and disadvantages of the two techniques.
18. What strikes you about the paint sample in fig. 17? How many paint layers are there? What strikes you about the thickness of these layers?
19. What colour pigments do you see in the paint sample?
20. What has this sample taught you about the paint layers of the painting from which it was taken? You might want to look back to the first assignment in this lesson.
21. Take another look at fig. 1 and indicate on your answer sheet, for each layer, which technique was used to discover this information.

Answer sheet

1.

layer	type of layer
1	
2	
3	
4	
5	
6	
7	

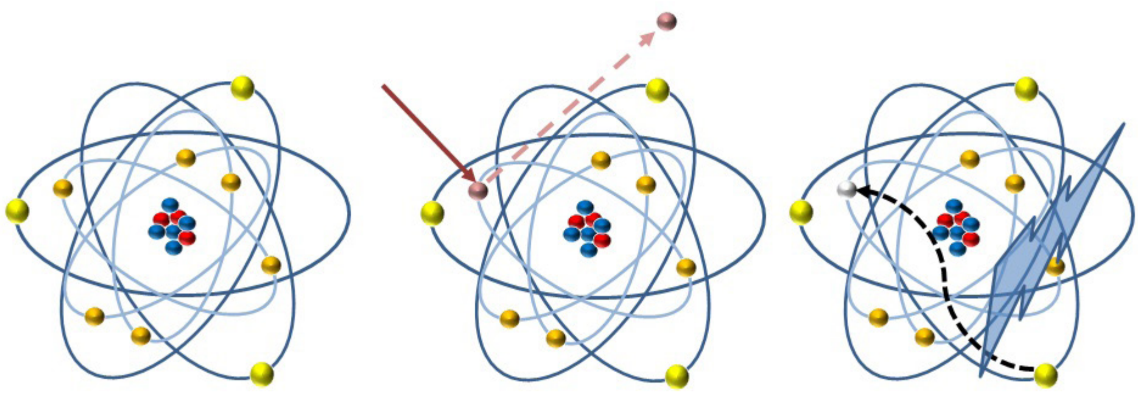
6.

light in X-ray	**dark in X-ray**
heavy / light element	heavy / light element
high / low mass number	high / low mass number

17.

	XRF	SEM-EDX
similarity in effect		
difference in effect		
advantage of use		
disadvantage of use		

12.



21.

layer	type of layer	research technique
1		
2		
3		
4		
5		
6		
7		

Literature

Van Gogh at work, Marije Vellekoop & Nienke Bakker. Van Gogh Museum / Mercatorfonds, 2013

Vincent van Gogh, The Letters: The Complete Illustrated and Annotated Edition [Hardcover], ed. Leo Jansen, Hans Luijten & Nienke Bakker of the Van Gogh Museum in association with the Huygens Institute. Thames & Hudson, 2009. 6 vols., 2,240 pages, over 2,000 illustrations.

Van Gogh: Master Draughtsman, Heugten, Sjraar van, 2005

Van Gogh. Paintings: The Masterpieces, Thomson, Belinda, 2007

Van Gogh in focus book series, a programme of publications about Vincent van Gogh and his times, the museum collection, recent research and exhibitions.

Vincent van Gogh. Paintings and *Vincent van Gogh. Drawings*: catalogues of the collection of the Van Gogh Museum. Several volumes, written by the academic staff of the museum. The books are obtainable from the Van Gogh Museum shop, in bookstores, and at **www.vangoghmuseumshop.com.**

Websites

You can find more information about research on Van Gogh's paintings at
http://www.vangoghsstudiopractice.com/
http://www.vangoghmuseum.nl/blog/slaapkamergeheimen?lang=en

You can find more information about Van Gogh's life and work at
www.vangoghmuseum.com
www.vangoghletters.org