LIGHT

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The students will learn about the nature of light, how it interacts with matter and how it allows us to see

Light mixes theory with practical activities. Even if the theory can get complicated given the topic, the project is designed at a low level, so everything could be understood without any previous knowledge. However, in order to introduce the concepts, translation will be needed.

It is a topic that every student can relate with, and there are practical activities and challenges that help understanding every concept. This makes the project a good asset if we want to introduce more theoretical topics to a group that is used to mainly practical lessons without scaring them away or losing their interest.

Skills:

- Collaborative working
- Problem solving
- Creativity
- Linking theoretical knowledge with the real life
- Presentation skills
- Talking in public

Learning goals

- Nature of light as a ray of photons
- Speed of light
- Classification of objects according to their behaviour towards light
- Reflection
- Refraction
- Decomposition of light. Colours
- How the eyes work

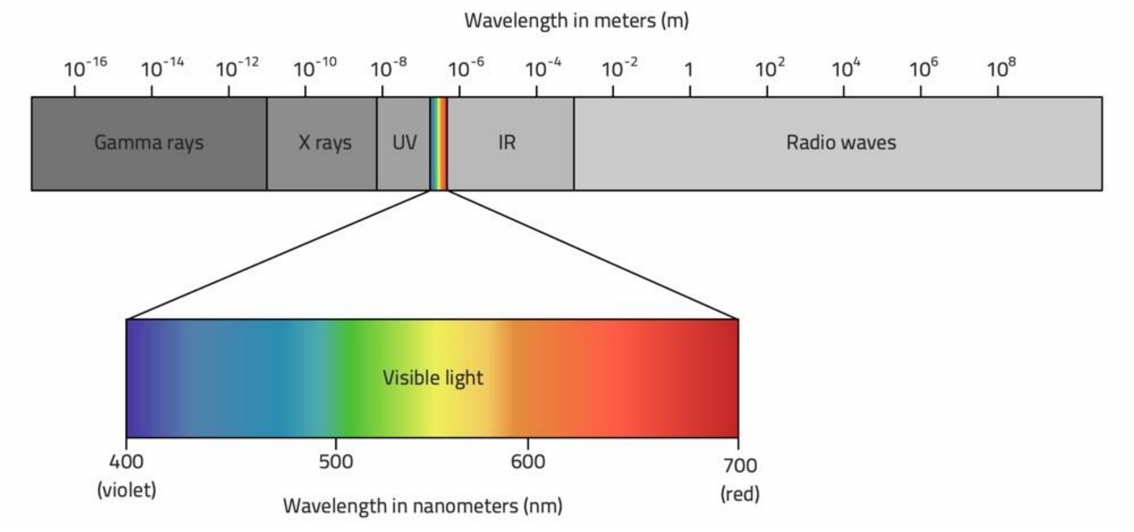
Lesson plan

Class 1: What is light? Objects according to their interaction with light.

The students will learn about the concept of photons. They will categorize objects into opaque, translucent or transparent and relate the categories with photons rebounding or going through the objects.

What do we need to know?

Light is electromagnetic radiation. The portion of the electromagnetic spectrum that can be perceived by the human eye is what we call visible light, and it is what we will focus on.



Picture 1 Electromacnetic spectrum

The nature of light is a very complex topic. It behaves at the same time as a wave and as a particle, what is called wave-particle duality. If we focus on its particle nature, the photon is the name that we give the particles that form a ray of light. Photons have no mass.

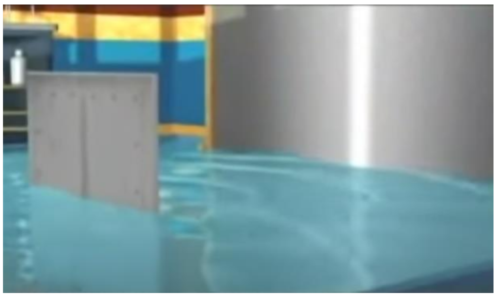
Matter can react in different ways when it interacts with light:

- If all the light is absorbed or reflected, then the object will be visible. These objects are opaque. Examples of them are wood, rocks or us.
- If all the light is allowed through the object, then we will be able to see through it. These objects are transparent. Glass, plastic foil or the air are example of transparent objects
- Finally, an object can reflect or absorb some light and let the rest go through, changing its direction when the light leaves on the other side. We can partly see through these objects, but the images we get of the other side are not sharp or clear. That is the case of thin paper or some kinds of fabrics. These objects are called translucent.

The reasons, explanation or consequences of light being both particles and waves at the same time exceeds the objective of this project. Therefore, we will not go deep on this theory. However, there is a simple experiment that shows a behaviour of light that supports this idea and that can be presented. It is the double slit experiment.

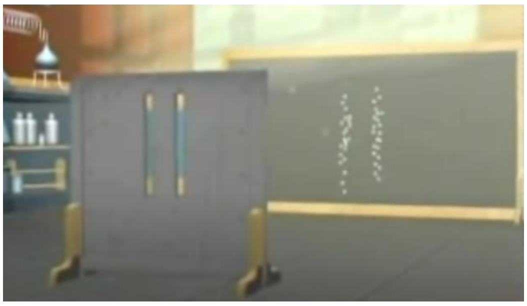
When light is shot through a narrow slit on a dark surface, the pattern that is seen on the other side looks like the one in picture 2. This makes sense with the idea of light being particles shot in a straight light. Otherwise, if light was a wave, what we should see on the other side would be something like picture 3.

Picture 2 Light behaving as particles

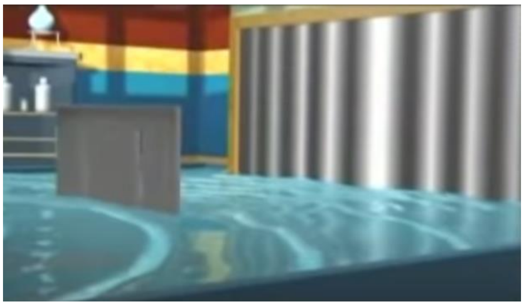


Picture 3 Light behaving as a wave

If now we make two slits, we would expect two marks of light on the other side, as shown in picture 4. However, what we will get is a pattern like the one in picture 5, that can be only explained by a wave.



Picture 3 Light as particles going through two slits



Picture 5 Light as a wave going through two slits

For a deeper explanation on this phenomenon, you can check the references. The shared video explains the experiment to prove the double-behaviour of electrons, but it was first observed using light.

What do we need to prepare?

- A dark room
- A torch
- At least one opaque object, one transparent and one translucent.
- If we decide to show the double slit experiment: media to reproduce an online video

Class session

The main purpose of the class is to get a first contact with the topic and to set the basic information that will be needed for the following sessions. The class will start in a dark room, where the students will not be able to see anything. The first question we will make is “why can’t we see?”. We will hopefully get the answer from our students: “there is no light”. We can then turn on a torch and bring a ray of light to the room. Using it we can introduce light as a ray of photons that are shot from the torch, traveling in a straight line.

The concept of light is much more complicated than that, but to the level that we want to get, this notion is enough. It is up to the teacher to evaluate if the students are prepared to move forward and try to understand light as particles and waves simultaneously.

After this little experience we can go back to the classroom. The aim from now is to understand the different ways light can interact with matter. For this, we will ask each student -or team, if we decide to make groups for this activity- to bring an object that provides light and another that do not. Once everyone has found their objects, we can have a look at those that don’t create light.

When we carried out this session it was interesting to see several students bringing a mirror as an object that provides light. They will get to understand the concept of reflection later in the cycle. We asked our students to provide light with the mirror, for which they pointed it to a lamp. Then, we asked them to do the same in the dark room. This showed them that the mirror was not a source of light by itself because it needed another source to reflect.

Among the objects the students bring there might be transparent and translucent. In case all of them are opaque, the teacher will provide some examples of these. Then, back in the dark room, they can shoot light from the torch to each different object. They will see the shade of opaque objects, and they will see no shadow when using a transparent object. In the case of translucent material, it will be something in between. Using this experience, we will try to guide the student to a conclusion:

- Some objects absorb or reflect all the photons, so they cast shade. These are opaque
- Some objects let all the photons through. These are transparent
- Others let some photons pass, but not all. These are translucent

If time allows and the students seem confident enough with the new knowledge, we could present them the double slit experiment. This will show them that light is much more complex than it looks like. Even if we know about it since the beginning of our existence, there is still a lot to be discovered. In the references an animation video explaining the experiment can be found.

Class 2: Speed of light

The students will learn about the speed of light. Through a game they will understand why we can see in the sky things that are not there anymore.

What do we need to know?

Light moving in the vacuum is the fastest thing that exists in the universe. It travels at approximately 300.000km/s. Nothing else can reach this speed. This is because the mass of an object increases as its speed increases. It is impossible to see in a small scale, but if a body would be accelerated to 10% of the speed of light, its mass would increase 0,5%. As speed approaches the speed of light, the mass tends to infinity, so the energy needed to accelerate the body and to get its speed even closer to the speed of light also tends to infinity.

The explanation of this phenomenon lays on the famous equation:

$$E = m \cdot c^2$$

but on its more general form:

$$E^2 = p^2c^2 \cdot m^2c^4$$

All these concepts and ideas are too high level for the class we intend to teach, but it is good for the teacher to have the knowledge in case they need to face questions.

Light can actually reach this speed due to two special characteristics:

- Photons have no mass, so the mass cannot increase.
- Photons are created already at its maximum speed, so they don’t need to be accelerated.

As interesting facts, the Sun is approximately 151 million kilometres away from Earth. This means that a ray of sunlight needs around 8 minutes to reach us:

$$\frac{151.000.000km}{300.000\ km/s} = 503.3s = 8.4min = 8\ minutes\ and\ 24\ seconds$$

This means that the light we see right now was sent by the Sun more than 8 minutes ago, so we can see where the Sun *was* eight minutes ago, not where the Sun is at the moment we look at it. This also implies that many of the lights we see in the night sky may be stars that died long ago, and only now we are receiving the light they sent. There may also be stars that were born too short ago for their first lights to have reached us yet.

What do we need to prepare?

No material is needed for this session

Class session

We will start asking our students to tell us what they remember from the previous session. Once we have made sure that everything was understood we will start a discussion about speed. We can initiate it by asking the class what are the fastest things they know.

We will spend some minutes listing fast things and the speed they can reach. It is likely that they will come up with light being the fastest thing in the universe since light is the topic of the project. Otherwise, we will introduce it and then we will ask them what they think is the speed of light. To give them an idea of how fast 300.000km/h is, if we could send a light from Greece to Australia it would go and come back 10 times in one second.

Distances on Earth are so small compared to the speed of light that it can see as if light would reach anywhere automatically, in zero seconds. However, distances in space are much larger. There we can notice how light does not reach its destination in zero seconds. We will tell our students the distance between us and the Sun: 150 million kilometres. Then, taking into account that light travels 300.000km in one second we will ask our students: “Does sunlight need more or less than one second to reach us?”

The answer to this question is simple. 300.000km is less than 150million km. Therefore, light will need more than one second to travel the distance. However, when a student hasn’t been properly introduced to Mathematics, comparing numbers that are higher than 100 or 1000 is not a simple task. In our experience, several students did not realize from the beginning that 300.000 < 150 million.

There can be some discussion around the question, or it might be clear for everyone that light will take some time. In any case, the next step is to calculate how long it will take. To find out we only need to divide the distance by the speed, and we will get 500 seconds. If we divide this by 60 seconds per minute, we will get approximately 8.4 minutes, what is eight minutes and 24 seconds.

Again we face a process that may be simple for some, but that can be very complicated for any student without a background in Mathematics. In order to avoid facing divisions from the beginning, if needed, we can approach in a visual way to find out the time light takes to reach us from the Sun. We can carry out the following activity:

We will go outside, or we will rearrange the classroom so there is empty space to move. One student will be the Earth, another one will be the Sun and a third one will be a ray of sunlight. To make things easier we will use the speed of light in kilometres per minute. That is, 18 million kilometres per minute. Each step of the light will be 18 million kilometres. Thus, every step will need one minute to be taken.

The Sun will be placed on one side of the room, next to the light. The Earth will not know yet where to be placed. We need to measure the distance. The light will make one step forward. Then we write down 18 million. The light steps forward again, and we will write 18 million again. Then we sum both together: 36 million. We need to reach 150 million to find where the Earth should be placed. Now that the activity is explained, the class can be divided in groups of three to do it at the same time. The Earth can be the one writing down the numbers and counting the steps.

We will let them some minutes to work, and eventually they should all be able to place Earth more than eight steps away from the Sun. Then we will ask the class “How many minutes does light take to reach us from the Sun?” To which the answer is “a little more than eight minutes”.

Our students will be aware now that the light from the Sun or other stars doesn’t reach us automatically. However, deducing from this that what we see in the sky is actually how things were in the past is not so simple. The Sun we see is the Sun as it was eight minutes ago. If the Sun exploded, it would take us eight minutes to realize. If the students struggle with this concept, we can continue the Sun-light-Earth game.

Picture 6 Group of students taking the role of the Earth

The Sun could now be any other star. The Earth will close their eyes and will only be allowed to open them once the light reaches them. Before leaving the star, the light will take a picture of it with their phone. During the time the light takes to travel, the star can do whatever they want. They can change their position; they can make a funny face. They can even disappear. Once the light reaches Earth, they will open their eyes and look at the phone. This is the information the light is bringing; this is what we can see from Earth. However, if we look at the star itself, maybe the current situation doesn’t correspond to what the Earth is seeing in the phone.

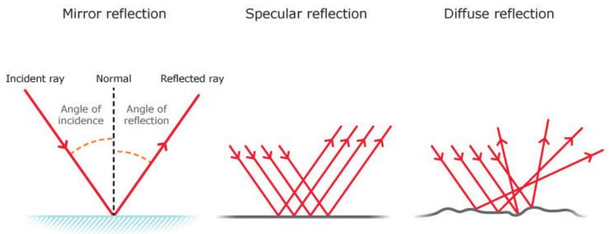
Class 3: Reflection in mirrors

To understand and experience how light rebounds in mirrors, the students will face different collaborative challenges.

What do we need to know?

When light hits an object, part of it may go through it, some may be absorbed, and the rest will rebound on the object. This rebounding is what we call reflection. The reflection of light allows us to see objects. The light that rebounds from them comes to our eyes and lets us see them.

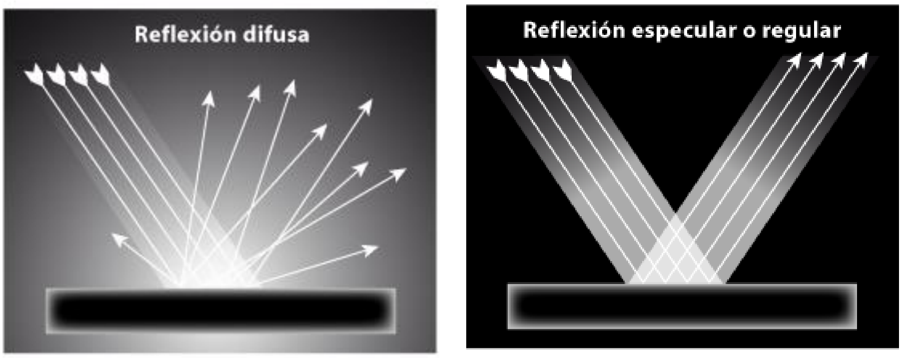
Usually, objects have a rugose surface. Even if they seem flat or polished, under a microscope we will realize that the surface is wrinkled or rough. This makes light rebound in all different directions. That, however, is not the case of mirrors. When a surface is polished it will reflect most of the light it receives in the same direction. This is the reason why we can see our reflection in polished surfaces.



Picture 7 Reflection of light on different surfaces

An interesting consequence of this, is that if we use a ray of light to illuminate a dark room, and we direct it to a non-polished surface, it will blur the light creating a halo of light. However, if we make it rebound in polished surfaces, we will be able to follow the ray, which won't be disseminated, but anything around the halo will stay in complete darkness.

Let's focus now on polished surfaces. If light hits the surface in a given angle, then the angle of the reflection will be the same one, but on the opposite direction, as seen on the picture.



Picture 8 Effect of the reflection of light in the dark on different surfaces

What do we need to prepare?

- One mirror per student
- Access to a dark room, or to cover any light entry in a room to create one.
- One torch
- Whiteboard and markers / blackboard and chalk
- Plans of the setting of both challenges
- Pens

Class session

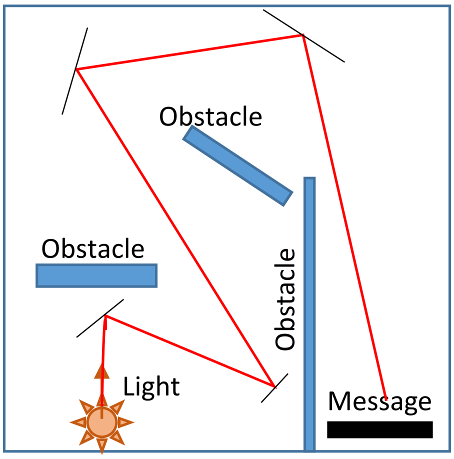
As we usually do, we will begin reviewing the previous lesson. Then, we will present the students a mirror. We will ask them what would happen if we shoot light to the mirror and if the light would do anything different if we shoot it at, for example, the table. We can allow some discussion around the topic, and finally we will conclude that in both cases light will rebound, or be reflected by the object. However, in the case of the mirror the light will not be disseminated, but reflected all in the same direction. Once this is understood, we will explain the two challenges that the class will have to face.

When we carried out these challenges, we divided the class into two teams of four and five people, and both teams worked simultaneously, each one on a different task. We were two teachers so we could as well split and support both teams at the same time. It worked very well, and both teams were able to concentrate on their challenge without worrying about the other team performing better. However, it is not always possible to proceed this way. It is up for the teacher to find the best way to organize the class given the number of students and their capacities.

Challenge 1: Reading a mysterious message.

This challenge will be set up in a dark room. There will be a fixed torch in the room, and a message written in one of the walls. Each student will have a mirror, so they can redirect the light from one mirror to another until they reach the message. To force all the students to participate, there will be obstacles for the light, such as furniture, so the light will need to travel around them.

In the following picture we present an example of a set up for four students:



Picture 9 Possible set up for the "secret message" challenge

Challenge 2: Finding the hidden person

One mysterious person will be standing behind a wall or a piece of furniture. One person on the team will be standing on the other side. He or she will be the observer. The aim of the activity is for the observer to discover who is hiding behind the wall.

The rest of members of the group will have their mouth covered, so they cannot talk. They will also have one mirror each. They will need to place their mirrors in a way so the face of the mysterious person is reflected from one mirror to the next until it is visible by the observer.

After every team finishes both tasks, we will provide a sketch of both settings to each team. They will have to draw the positions where they placed themselves when they solve each task. Then, they will have to draw the path that the light travelled in each case.

Finally, two people chosen by us will stand up on the whiteboard to explain to their classmates how they solved one of the tasks using the sketch and the paths they had drawn.

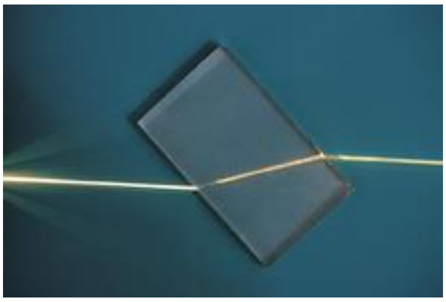
Class 4: Refraction

The students will learn about the change of speed of light when it moves from one mean to another by seeing the deformation that pencils seem to suffer when they are put into liquids.

What do we need to know?

Refraction is the change in direction of a wave that occurs when it passes from one medium to another. This change happens because the wave is slowed down or accelerated when it changes the medium.

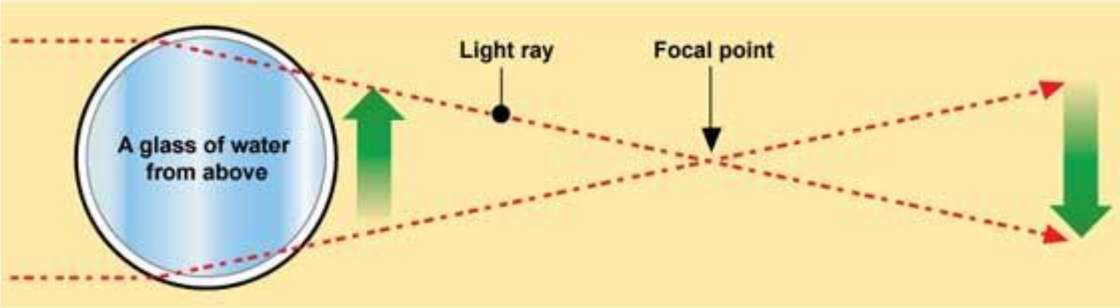
Imagine you are in the beach. As you walk into the water your speed will decrease because moving inside the sea is harder than doing it outside. For the light something similar happens. When it goes from air to water, it slows down



Picture 10 Refraction of light on a piece of glass

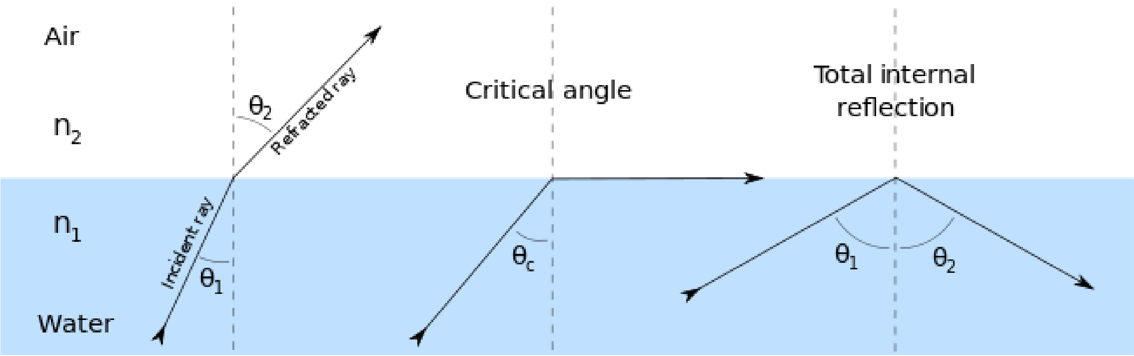
inside each medium the speed of light will be different, and according to that, we will see objects that we place inside the medium more or less deformed. The closer the speed is to the speed in the air, the less deformation we will see.

When light goes through a glass of water, for example, the light is bent several times. First going from the air to the water, then leaving from the water back to the air. This explains experiences like the turning arrow: If we paint an arrow in a paper and place it behind a glass with water, the arrow will appear to point in the wrong direction.



Picture 11 Explanation of the turning arrow experience

The angle that the ray hits the new medium is called angle of incidence. The new angle, once the light s inside the new medium, is the angle of refraction. As we modify the angle of incidence, also the angle of refraction will change. If we make the incidence larger and larger, at some point, the new angle will be facing to the current medium, so the light will actually not be able to pass to the new material, as you can see in the image:



Picture 12 Relation between the angle of incidence and the angle of refraction

What do we need to prepare?

- Plastic transparent box full of water
- Plastic transparent bottle full of water
- Something to make a whole in the bottle
- A laser beam
- A set of transparent glasses full of different transparent liquids
- Pencils
- A dark room

Class session

When everything learnt in the previous session has been reviewed we can start with the new class. To begin with, we will place an empty glass cup in the middle of the class. Then, we will place a pencil inside and ask the students if they see anything strange. The next step will be to fill the glass with water.

The students will realize that the pencil seems to be broken. After letting them discuss why they think this happens, we can introduce the concept of refraction. We can now perform the arrow experiment as well, to have a second visual experience of the phenomenon of refraction.

The last part of the class will consist of some experiments performed in groups.

When we did these experiments, we divided the class into two groups of four and five students. While one team worked in experiment 1, the other performed experiments 2 and 3. When everyone was done, we swapped. This allows everyone to be working at the same time and provides a quiet space for both teams. However, the way of organizing the workflow depends on the characteristics of the class and the amount of students

Picture 13 The pencil seems to be broken due to refraction

Experiment 1: Ordering from faster to slower

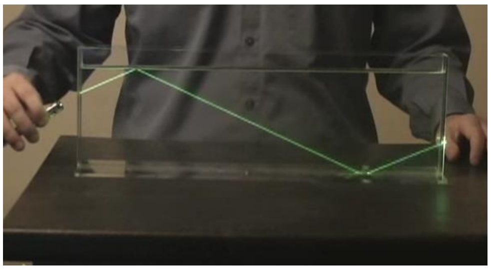
The group will receive a set of glasses full with different transparent liquids. The task will be to place a pencil inside of each of them and observe the deformation of the pen. According to the observations they will have to order the liquids from the one where light travels fastest to the one where it travels slowest. We used water, oil, alcohol and soap. The order in this case is:

water > alcohol > soap > oil

Measuring liquids with refractive indexes that are close to each other, like water and alcohol, can bring the problem of swapping them around, since we are measuring by observation without using proper measuring tools. It would be advisable to try out different liquids that are available before doing the class and choosing those on which the differences on refraction are more obvious.

Experiment 2: Finding the critical angle in water

The students will go to a dark room to make the experience easier. We will have prepared a plastic transparent box full of water, and a laser beam. The students will shoot the beam from the side of the box, pointing to the surface. By changing the angle of incidence, they can make the laser go out of the water or rebound and stay inside.

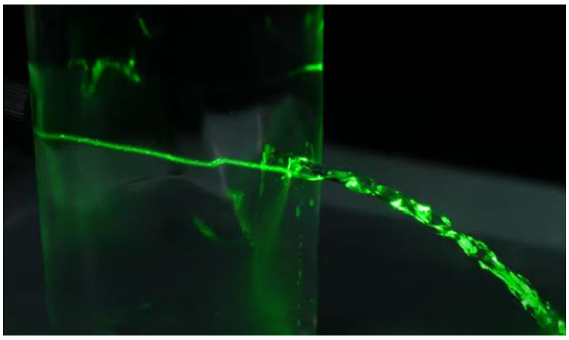
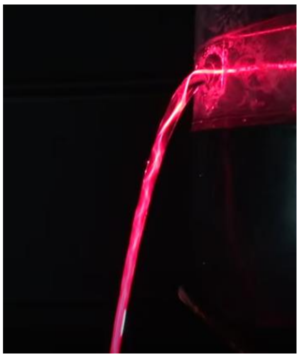


Picture 14 The laser rebounds and stays inside the water due to the angle of incidence

Experiment 3: Does light travel in a curve?

We will place a plastic bottle full of water next to the plastic box, and we will make a small hole from which water will pass, as a waterfall, from the bottle to the box. If we point the laser from the back of the bottle to the hole, we will see the whole stream of water illuminate, as if the light was traveling through the waterfall, doing a curved path.

The students will have to reason that what is actually happening is that the light rebounds on the water over and over again, moving down the stream, but traveling always on a straight line

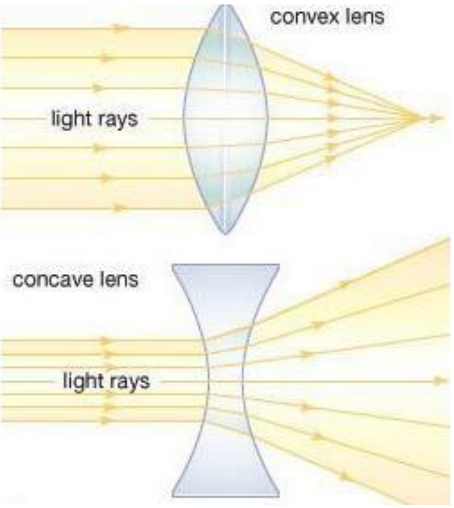
Picture 15 Two examples of light trapped on a waterfall. In the second one it is easy to see how the laser gets reflected within the water stream

Class 5: Lens to focus light

The students will learn how lenses focus light and use that knowledge to explode balloons.

What do we need to know?

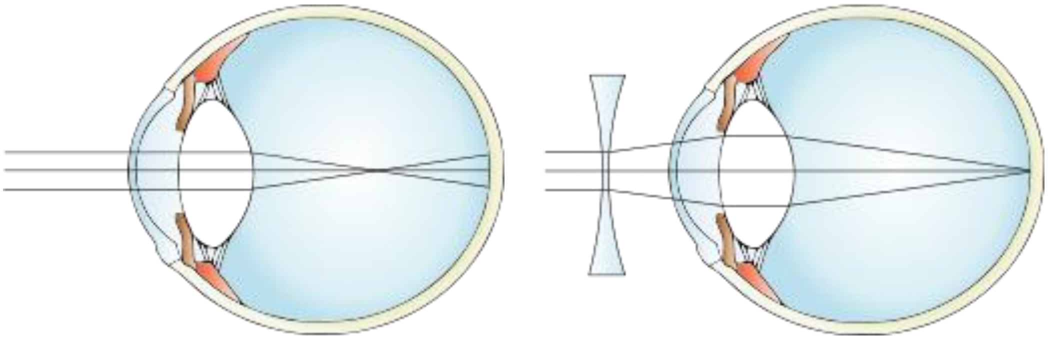
In this class we will talk about lenses. A lens is a device that focuses or disperses a light beam. The change of direction that happens in the light and allows the dispersion or the focus is due to the refraction that happens inside the lens. There are different kinds of lenses. The convex ones can focus all the light that goes through on one point. The concave ones, however, will disperse the light.



Picture 16 Effect of lens on light

A magnifying glass is a biconvex lens. Its structure helps focusing all the light in one point. This point will receive much energy, so it can get hot very quickly. This is how magnifying glasses are often used to burn things.

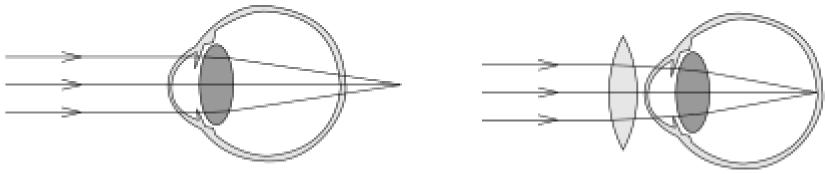
It is interesting to link this topic with the usage of glasses. Two of the most common visual problems are myopia and farsightedness. People with myopia cannot see objects that are far away. This is because the point where their eye is focusing the image is before the retina. To solve this problem, concave glasses are used. They disperse the light so it is further apart when reaching the eye. Then it is focused by the eye, and the image



Picture 17 Eye with myopia and how lenses help focusing on the retina

reaches further back in the eye, in the retina. These kinds of glasses make the eyes of the person wearing them look smaller than normal.

Farsightedness is the opposite case. People with this disease cannot see object that are too close because the image are focusing behind the retina. To solve this convex lenses are used, to concentrate the light even more before reaching the eye. People with high levels of farsightedness wear glasses that make their eyes look bigger than normal.



Picture 18 Eye with farsightedness and how lenses help focusing on the retina

Finally, to teach this class we will need some information about the theory for the following session. We will only mention here what we need to know, and will develop the information in the next session.

Depending on the colour of an object it will tend to absorb more or less light. The energy that the object absorbs from the light will make it heat up. Objects that are white do not absorb light at all, while black objects absorb all of it. This is the reason why white objects heat up slower than black ones when they are in the Sun.

What do we need to prepare?

- Coloured balloons. Among them, we will need back and white ones
- Magnifying glasses

Class session

To carry out this class we need the light of the Sun during the central hours of the day. If the Sun is too low, its power will not be enough, and artificial light will not work.

To begin with, after reviewing the previous class, we will present the class a magnifying glass and ask what they know about it. The answers we are looking for are that they make things look bigger and that they can be used to burn things. Once the students have reached this point, we will ask them why they think lenses can do these things.

Painting in the whiteboard we will show how lights entering a lens are redirected and focused in another point. We will explain this as a refraction process, as we discussed in the previous class.

Finally, all the students, either in groups or independently depending on the materials available, will get balloons of different colours and a magnifying lens. Their task will be to make them explode, and count for each colour how long they take to explode. Among the balloons, every group will have a black one, that will be the one exploding the fastest, and a white one, that will probably not even explode. Once every team is finished the class will end.

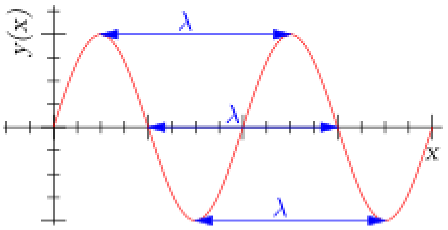
Our students got very curious about the white balloon not exploding. We used this as a cliff-hanger for the next session, and invited them to do their own research about the topic before the next class.

Class 6: Decomposition of white light: colours

Through a game the students will get to understand why different objects have different colours. They will deduce the special characteristics of white and black.

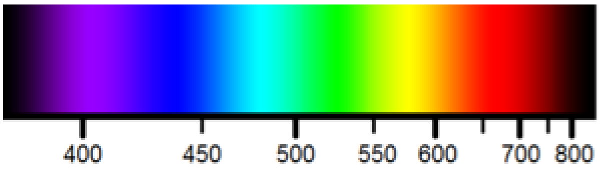
What do we need to know?

Light can be considered a wave, and every wave has a wavelength. This is how wide the wave is. Imagine two people shaking a jumping rope. The rope will produce waves, and the faster and stronger the people shake, the closer together the waves will be. When the waves are closer together they will have a low wavelength. Otherwise, they will have a large wavelength.



Picture 19 Wavelength of a wave

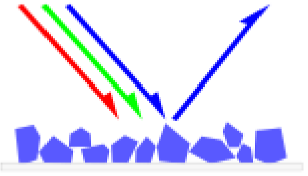
Our eyes can see waves with a wavelength between 380nm and 780nm. Each and everyone of these frequencies are recognized by our brains as a different colour.



Picture 20 Visible colours according to their wavelenght

Light does not usually consist of one and only frequency, but a mixture of many of a range of them. When all of them are present at the same time, we see the colour white. This is the case of the sunlight. It contains all the frequencies in our visible spectrum. This means that inside the sunlight we can find all the visible colours.

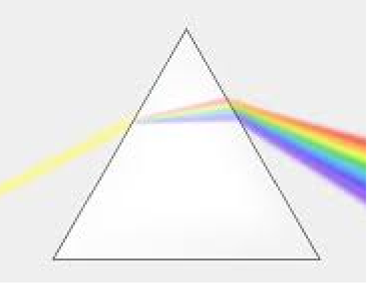
However, when the Sun illuminates objects we don't see everything white. Different matter has different colours. The reason is that every opaque object can absorb certain wavelengths, but not all of them. Those that cannot be absorbed are reflected, and these are the ones reaching our eyes. A blue object will absorb the wavelengths that are not blue. The blue wavelengths will rebound, and they will reach our eyes, making us recognize the object as blue.


Picture 21 Behaviour of blue objects when they recieve coloured light

White objects do not absorb any waves. Since everything is reflected, they seem white. On the other hand, black objects absorb every single wavelength, not reflecting anything. For this reason, when exposed to the Sun, black objects tend to get hot faster. They absorb all the energy.

This has funny consequences when we expose objects to coloured light. If we are in a dark room and turn on a red light, all the red objects of the room will appear red, because they will reflect all the red wavelengths. However, if we look at any non-red object, it will absorb the red light, and since there is no other wavelength to reflect, the object will appear to be black.

Finally, when talking about colours we cannot forget the rainbow. This natural phenomenon is caused by the decomposition of white light due to refraction. Refraction is the change of direction that light suffers when passing from one medium to another. This change can happen differently for different wavelengths. A classic example of this is the effect of an optical prism



Picture 22 Decomposition of white light going through a prism

When white light enters, the larger wavelengths, that produce red colour, change direction in a smaller angle than smaller wavelengths, like violet. The different lengths are not mixed anymore, but organized, so we don't see white anymore. We see all the different colours that were composing the white light. Traditionally, they are considered to be red, orange, yellow, green, light blue, dark blue and violet.

After rain, every water drop in suspension in the air will act as an optical prism, and the sunlight going through them will make a rainbow appear in the sky

What do we need to prepare?

- A glass
- Paper
- A bowl with water
- A torch
- A dark room
- Coloured light. For example, the red light of a headlamp
- Objects that are the same colour as the light
- Objects that are not the same colour as the light
- *Light rays*

We will need to build some kind of white item that is built with -or contains- a piece of each of the seven colours of the rainbow.

When we did this class, we printed and coloured a wooden structure to work as light rays. The different coloured parts could be removed. Easier approaches can be taken, like a hollow white ball full with seven pieces of coloured paper, or even a white paper folded and containing seven pieces of coloured paper.

Picture 23 The teachers holding some of the "light rays" used for this class

Class session

Through the reviewing of the last session we will get to the topic of the class: colours. The colour of the balloon affected how long it needed to explode. But why?

We can start asking the class where, in nature, we can find all the colours. The answer is the rainbow. We can then ask if the colours of the rainbow are always in the same order, and what order it is. To check their answer, we can project a small rainbow on a paper using a glass and a torch.

Now we can explain the theory of the class on the whiteboard. We will explain how the different wavelengths code different colours, how they are all inside the white light, and how optical prisms or water can organize the lengths by refraction. Last, we will move to why different objects have different colours.

Picture 24 A rainbow produced with a mirror, a bowl of water and a torch

It is easy to understand that objects absorb only some wavelengths. What might be complicated to internalize is that the object will not absorb the colour we see. To make that clear, we will play a small game. The students will be divided into small groups. The activity can be done in pairs if there is enough material.

One student will have a ray of light, and will shoot it at an object. Another student will take the ray and, according to the colour of the object, will take out of the ray the colours that are absorbed by the object, Then, he or she will throw the ray back only with the colours that the object reflects. For example, one student can throw the ray to a blue T-shirt. Then the next student will open the ray, take out all the colours except from blue, and throw the ray back to the first student.

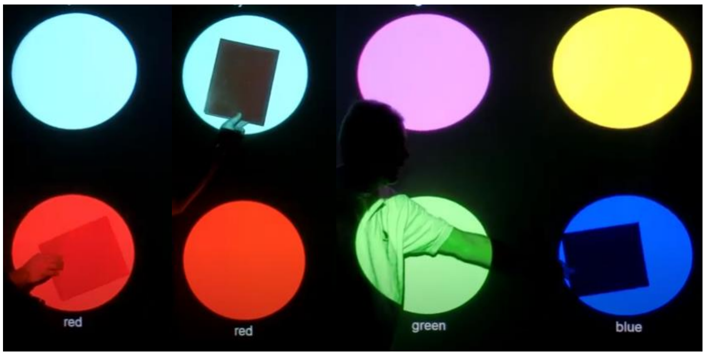
When we held this class, what wavelengths are absorbed and which are reflected was very easily understood. The nature of black, however, took some time for some teams to understand. Other teams got it very fast, and they had to wait until everyone had made their conclusions to continue the class. The teams that conclude that black absorbs everything got bored of waiting and started disturbing the class, making it even more difficult for the other teams to work.

To avoid this, it can be an option to have complicated questions prepared, like the one about coloured light that will be presented in the following paragraphs. These extra challenges can keep the faster teams busy and interested while the slower ones reach the minimum knowledge we expect to be gained through the session.

As the activity goes, we will have to make sure that every team works with the colour white, and concludes that every colour should be left in the ray. They also have to work with the colour black, and we will guide, if needed, their thinking process to see that in that case all the colours should be kept, so nothing is sent back.

Once the nature of black and white are understood, we can do a little performance to see as well why white objects heat up slower than black ones. One student will be colour white. Then, all the students will start throwing him or her light rays. Since white reflects everything, he or she will just send them back as soon as they reach. Next, one student will be the colour black, and we will repeat the exercise. In this case, the student needs to keep everything that is received, so soon he or she will have a pile of rays to deal with.

Finally, if there is time, we can make a last experiment. We will present our students a coloured light, and we will ask them what wavelength it is formed of. Does it have all the colours inside? The answer is *no*. Only the wavelengths corresponding to its colour are present. So, if we shoot a red light to an object that is red as well, the light will be sent back and we will see the colour. If we shoot it to a white object, which usually reflects all light, this object will appear to be red as well. Otherwise, the wavelength of the light will be absorbed and nothing will be reflected.



Picture 25 The same red folder under different coloured light

When that happens, an object seems to be black. To experience this, we can turn off the lights and look at different objects under a coloured light.

When doing this experiment, use objects with very different colours from the light. For example, if the light is red, blue objects will seem completely black, while orange or yellow ones will seem reddish, since they partly reflect red light.

To end the class, coming back to the beginning, we can ask the students if they can come up with a way to explode the white balloon. If they paint a dark spot on it and focus the light on that spot, the balloon will easily explode.

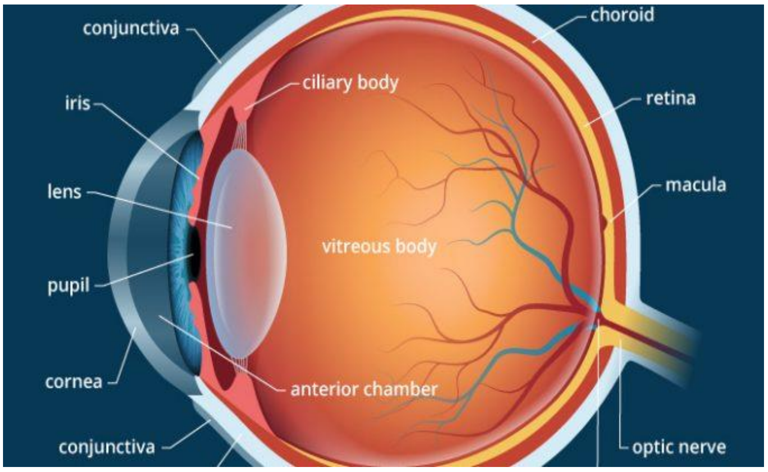
Picture 26 The teachers exploding a white balloon by painting a dark spot on it

Class 7: The eye

Painting a picture that is only visible through a hole on a sheet student will understand how images are painted in the back of our eyes

What do we need to know?

The main objective of this class is not necessarily to understand the full anatomy of the eye, but to focus on how light stimulates the retina "painting" images on it. However, in order to be prepared to explain something we believe that it is necessary to have a clear idea of the bigger picture. Therefore, we will include here information about all the parts of the eye and their functions, even if not all this information will be needed during the session.

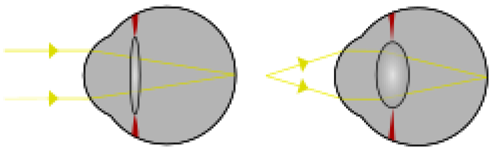


Picture 27 The different parts of the human eye

Covering the front of our eyes we have the cornea, what is a transparent protective surface. When light goes through it, it gets refracted. Then, light goes inside the eye through the pupil, the small black hole in the middle of the eye.

Around the pupil we find the iris, which colour changes from one person to another. Its function is to close and open the pupil according to the amount of light that is received. When there is not much light, the diameter of the pupil will be increased so as much light as possible can go in. In very illuminated environments, the opposite will happen.

Once light enters the eye it will have to go through the eye lens. These lenses are biconvex, like a magnifying glass, and they can change their shape depending on where we want to focus our sight. If we want to look at distant objects, they will flatten. If we want to focus on things that are closed to us, they will enlarge, as in the following picture:



Picture 28 The eye lenses changes shape depending on where we want to focus

Moreover, light will need to go through a liquid environment when passing from the cornea to the lens, and again when moving from the lens to the retina. In both cases, refraction will happen.

Finally, light will reach the retina. The retina is a layer of cells in the back of our eyeballs. These cells are photosensitive. This means that they react to light. We have around 65 million of these cells in each eye. 60 million of them are called rod cells. They are responsible for sensing the light and allow us to see black, white and the grey range. They work well in the dark, so are the main responsible of night vision. The other 5 million are called cone cells and allow us to see colours. They work well in well illuminated environments. A person with a normal vision has three kinds of cone cells. One can respond to blue light, another one to green, and the last one, to red. People that are colour blind usually lack one of them.

When light is reflected back from an object to our eyes, the photosensitive cells in our retina get activated and in simple words, paint a picture in the back of our eye. Then, each cell sends its part of the picture to the brain through the optical nerve using electric pulses, and the brain interprets the image. Then, we can see.

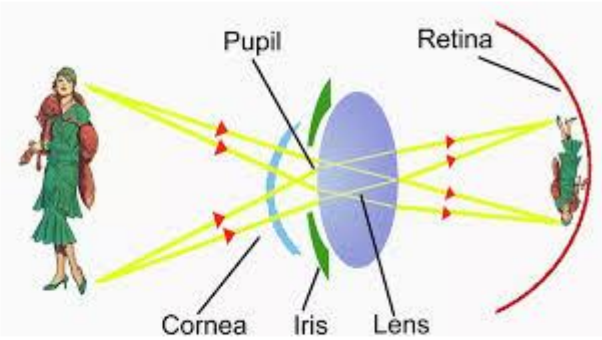
As an interesting fact, the place where the optic nerve connects with the retina has no photosensitive cells. Therefore, we cannot see anything that reflects light exactly to that point. This means that on each eye we have a blind point. Since this point is different on each eye, it doesn't affect us unless we only use one of our eyes.

It is easy to spot the blind spot using something like the picture below. If we close one eye and focus on the image that is on the opposite side of the eye the we closed, after adjusting the distance to the picture we will stop seeing the other image.

Picture 29 Sample image to find the blind spots of our eyes

Now we get to the main part that we want our students to understand in this class. When the image is recreated in our eyes, it is inverted. This means that everything is painted upside down in our eyes. Then our brain needs to put it back in the right position. To understand why it happens we can simply look at the following image:

Light that comes from the top of an object travels in a straight line and lands on the bottom of our retina. The opposite happens for light coming from the bottom of an object.



Picture 30 Diagram of how our images get inverted when they travel through our lenses and are interpreted on our retina.

What do we need to prepare?

- A big sheet to hang in the classroom. If we do the activity by groups, one sheet per group
- Two big sheet of paper per group
- One empty toilet roll per team
- Different colour markers
- Something to hang between the sheet and the papers in the classroom
- A laser beam per team

Class session

We have seen already how light works, its nature and how different frequencies compound the colours that we see. Today we will look inside of ourselves to learn how we interact with light.

To begin with we can ask our students how light affects different materials. For example, it can heat up surfaces, it can tan our skin, and it can paint certain materials, such as photographic paper. From here we can move to our retina, and how we have cells that can be painted by light.

It depends on the group and the set up of the class how much into the structure of the eye we can go. It is a very interesting and catchy topic, but it would take a whole session, or even several if there is a need for translation. When we held this class we didn't talk at all about the different components of the eye and just mentioned that it gets painted and images are sent through a nerve to the brain.

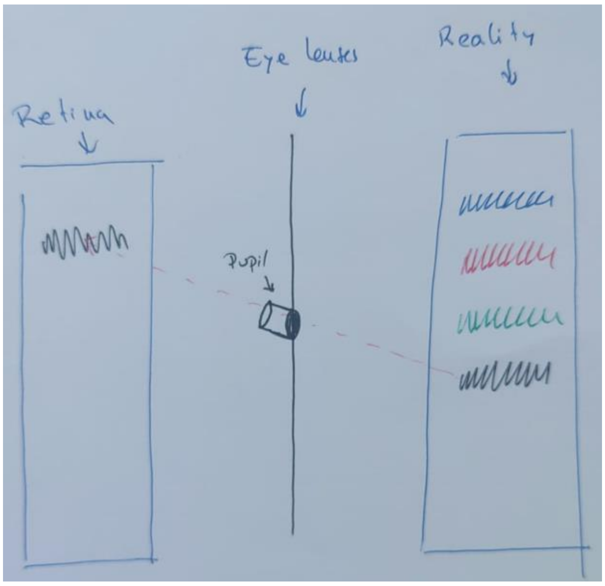
After giving a brief explanation of the theory we will do an activity where the students will be the retina cells and will have to paint an image in the back of an eye. A sheet will be hung, separating the eye from the outside world. In the middle of the sheet, we will make a small hole, the size of a toilet roll. This will be the pupil. On the eye side, we will have a paper sheet where the students will paint what they see.

On the other side of the sheet, on the outside world, we will hang a paper sheet with a set of colours arranged in a horizontal line. The task is to replicate the colours in the inside paper sheet by looking through the hole using a toilet paper roll.

The important part of the activity is that everything will have to be painted following the direction on what the student is looking at. As shown in the picture.

To show where the painting should happen, the teacher, or one of the students, will be outside of the eye, and will point a laser beam through the hole from the point that the students are looking at. The beam will mark, on the other side, where the painting needs to happen. The result will be a copy of the combination of colours that we provided at the beginning, but upside down.

We held this class with only five students, so we set up one sheet and all the students worked together as a group. We think this activity can easily be carried out in groups of five or six students, if each one has one colour to look at through the sheet.



Picture 31 Diagram of the exercise. The students will be looking through the "pupil"

Class 8: Building a pinhole camera

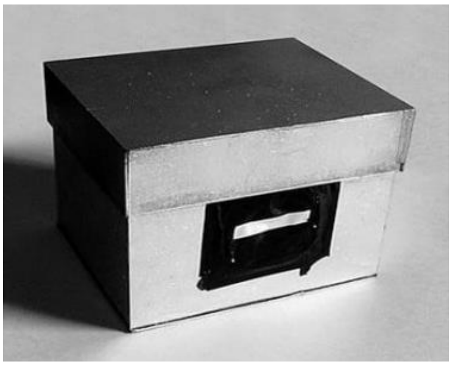
Using a carton box each student will build a camera that they will use in the excursion.

What do we need to know?

A pinhole camera is a very easy-to-make item that will allow us to experience how light makes images in photosensitive material. The instructions and materials to build one are as follows:

Material:

- Photographic paper
- A carton box, the size of a shoe box or slightly smaller. It has to be at least big enough to have the photosensitive paper against one of its walls.
- Black paint
- A can
- A needle
- Sandpaper
- Black electric tape



Picture 3210 Pinhole camera

Instructions

- In one of the sides of the box, the one opposite to where the photo paper will be, cut out a 2x2cm square.
- Cut a 4x4cm square out of the can
- Make a hole in the middle of the metal square using the needle. This will be the pinhole.
- Sand the hole to make it smooth
- Using electric tape, stick the pinhole inside the box, centred on the squared you cut out before.
- Paint the interior of the box black
- Make sure the box is completely sealed and no light can go inside apart from the pinhole. If needed, add electric tape to cover any holes.

If we place a photosensitive paper inside the camera, facing the pinhole, and expose the box to light, the light will enter through the hole and hit the paper. This kind of paper is not sensitive to colours. It just gets darker as it is hit with light. The more powerful the light that hits is, the darker the paper will become. Therefore, if we have a white object, that reflects all the light, it will appear in the paper as black, because the paper will receive all the light reflected from the object. If an object is black, it will reflect nothing, so in the paper there will be no mark of light and it will stay white. This means, our result will be a picture in black and white with the colours inverted. A negative of the picture.

Picture 32 Result of using a pinhole camera

It is extremely important that there is no opening in the box apart from the pinhole, because any light will make the paper turn black.

What do we need to prepare?

- A carton box per student. We can also ask them to bring a box from home
- Several rolls of black electric tape
- One can for every two students
- Scissors strong enough to cut a can. A cutter knife is a good option
- Needles. One for every two students
- Black paint. It can be water-based paint, acrylic… Spray paint can be good option because it dries out very fast, but it needs to be used in an outside area
- A piece of sandpaper for each student

Class session

The first part of the class will be explaining what we are going to do, and how the camera will work. Once the students understand this, they can build their own camera that will be used in the trip.

In the references and extra material for this project you can find an experiment that shows how this kind of camera works without needing photosensitive paper. It could be done in case of a lack of materials or darkroom to do the development. Also, it could be done before building the camera, if time allows.

To make the session flexible to the pace of each student, we will give everyone the materials they need and the instructions to make the camera. Then, everyone can work independently. As soon as a student is done with their work, they can leave.

Evaluation

To test the knowledge that our students got during this cycle we will organize an escape room from which they will have to flee. Inside the room they will find three different challenges, and solving each of them will give them a part of the combination to open the lock that keeps them in the room.

For each challenge they will have three possible answers and they need to choose the correct one. The correct answer will give them a number to put in the lock, and the position of that number. Giving the position as part of the information, we avoid the students randomly trying all the answers of a challenge, since they would need to combine them with the positions of the answers of other challenges. If they know for sure the correct answer for two tasks, then they can guess the right solution for the third by checking which option gives a number in the position they need, but then they would at least prove that they are certain about their knowledge on the other questions.

The room will be in complete dark. Only one torch will be on, shooting a beam of light. The torch will be fixed and will not be movable. Each student will have a mirror, and they can use them to reflect the light towards the different challenges, so they can read and solve them.

The challenges

1. Find a balloon that reflects all the light that it receives.

There will be several balloons around the room. Only one of them white. Inside each balloon there will be a paper with a number for the lock, and its position. They need to explode the white one, where the correct information is hidden.

Needs:

- Several coloured balloons. At least 2
- Small papers to put inside the balloons, with the answers, before inflating them.

2. Find the liquid where light travels slower

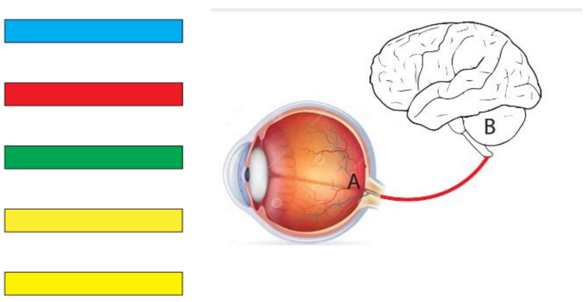
There will be three glass jars filled with different transparent liquids, each of them labelled with a possible number for the lock, and its position. inside each of them, there will be a pencil. The students need to realize that the one where the pencil looks more broken is the one where light gets more refracted, and, therefore, the one where light travels slower.

Needs:

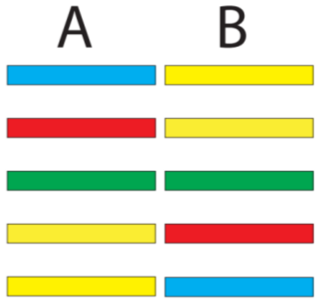
- Three glass jars
- 3 labels
- 3 pencils
- 3 liquids with different refraction rates. For example, water, oil and soap.

3. Choose the picture that shows how certain image looks in our eye, and how it looks in the brain

We will hang in the room something like the following. There will be several possible answers to the situation. One could be the one in picture 34, that would be incorrect. The sequence of colours should be inverted on the eye (A) and the real one on the brain (B)



Picture 33 Instructions we used for the challenge



Picture 34 Possible, but incorrect answer

Needs:

- 3 posters with the different options

Escaping challenge

To make it more fun, we can place a laser beam in front of the lock, and reflect it with two mirrors, making an invisible laser barrier. To make it visible, the students will turn on a smoke machine. The smoke will show the beams, and the students can place their mirrors to reflect them away from their way before moving to the lock.

All this material is very difficult to access in normal settings. We designed the escaping challenge like this because we had these machines, so we found ways to use them to make the class more fun. In other settings it is up for the teacher to change, adapt or simply remove anything that is too challenging to implement

Needs:

- Smoking machine
- Laser beam
- At least two mirrors

Implementation

We will divide the students into groups of four. Each team will enter the room once the previous one has finished. We will explain to everyone how the exam works some minutes before starting, so every team is ready to start as soon as they enter the room.

One teacher will enter the room with each group, lock the door and set a timer for thirty minutes. From the moment the timer starts the students will be on their own, with the teacher as a simple observer. If the students free themselves before the timer finishes, then the group passes the exam.

Showcase

The students will be divided into teams, each of which will present a part of the theory that they studied. Each group will be allowed to prepare their own material.

Extra class: developing pictures

During the project or students built pinhole cameras. Now is the moment for them to use them and develop their pictures.

How to use the camera.

- In a dark room, using red light, place the photosensitive paper inside the box, on the opposite side from the pinhole. Make sure that the light-sensitive side is facing the pinhole
- Fix the paper to the box with double-sided tape. Avoid touching the paper with your fingers, try to touch only the sides.
- Close the box and make sure no light can enter. Fix the lid to the box with electric tape covering any possible entrance if needed.
- Cover the pinhole with electric tape

- Take the camera to the place where you want to take the picture.
- Remove the tape from the pinhole and leave the camera for 25 seconds if you are outside in the sunlight, or up to five minutes if you are inside, using artificial light.
- Cover the pinhole with tape again

Needs to develop the pictures

You will need at least two liquids: a developer and a stop bath to stop the developing process. You can also use a fixer bath to fix the image, but it is not essential. You can get in touch with any local photography shop to get the liquids and indications on how to use them. If it is not possible, you can make the liquids at home.

For homemade developer

- Stir 10g of dried mint leaves into 200ml of hot water.
- Brew for 15 minutes, then strain through a coffee filter into a new container.
- In another container, add two 100mg vitamin C tablets to 200ml cold water.
- Gradually add 10g of bicarbonate of soda while stirring.
- Mix the two solutions and leave for 10 minutes so all the bubbles settle.

For homemade stop solution:

- Mix 5ml of lemon juice with 200ml of water.

How to develop the pictures.

- Place each liquid in a shallow wide container that can fit the photographic paper
- For each solution, take a pair of kitchen's clamps or something similar to take the pictures
- Enter the darkroom and open the pinhole camera
- Introduce the paper in the developer solution. Try not to touch the paper
- If you are using a homemade mint based solution, leave the picture on it for two minutes. Otherwise, check the instructions of the solution
- Using the clams take the picture out of the liquid and place it into the stop bath
- Wait 30 seconds -or what the instructions state- and take the picture out with the clamps
- If you have a fixer bath prepared, then place the picture in the next container and follow the instructions that you have.
- Otherwise, rinse the paper in plane water and leave to dry

When we used the cameras with our students, only one of the pictures worked properly. We don't know for sure what went wrong, but we have some ideas on where the risk factors laid. We took the pictures far away from our working place, so we needed to travel for half an hour with the papers already inside the cameras, and then half an hour more after the pictures were taken. This increased the probability of light going into the box and damaging the image. Besides, the liquids that we used had been in the containers for 3 days. We prepared them some days before to test them, and we used them to develop a picture that we did. It could be that the liquids were not suitable for developing anymore, so we recommend to prepare the solutions right before the session.

EXTERNAL RESOURCES

- Video about the double slit experiment:

  https://www.youtube.com/watch?v=Q1YqgPAtzho

- Video tutorial to make the laser trapped in a waterfall experience:

  https://www.youtube.com/watch?v=WC_qcNDFK7s&ab_channel=RonyesTech

- Video explaining why objects with mass cannot reach speed of light:

  http://lahoracero.org/por-que-no-se-puede-ir-mas-rapido-que-la-luz/

- Video showing how to make a rainbow:

  https://www.youtube.com/watch?v=5MPfA3q42Os

- Video about the colour of different objects under different coloured lights

  https://www.youtube.com/watch?v=_goD-vZdgg8&ab_channel=JoelBryan

- Experience with a pinhole camera without paper:

  https://kids.nationalgeographic.com/explore/books/pinhole-camera/

- Tutorial to develop your pictures making your own solutions

  https://www.youtube.com/watch?v=O4bf2IO3-Wg&t=71s&ab_channel=TheRoyalInstitution

- The whole process of taking a picture, from putting the paper to developing it

  https://www.youtube.com/watch?v=f6WX0o33pk0&ab_channel=TheModernRogue