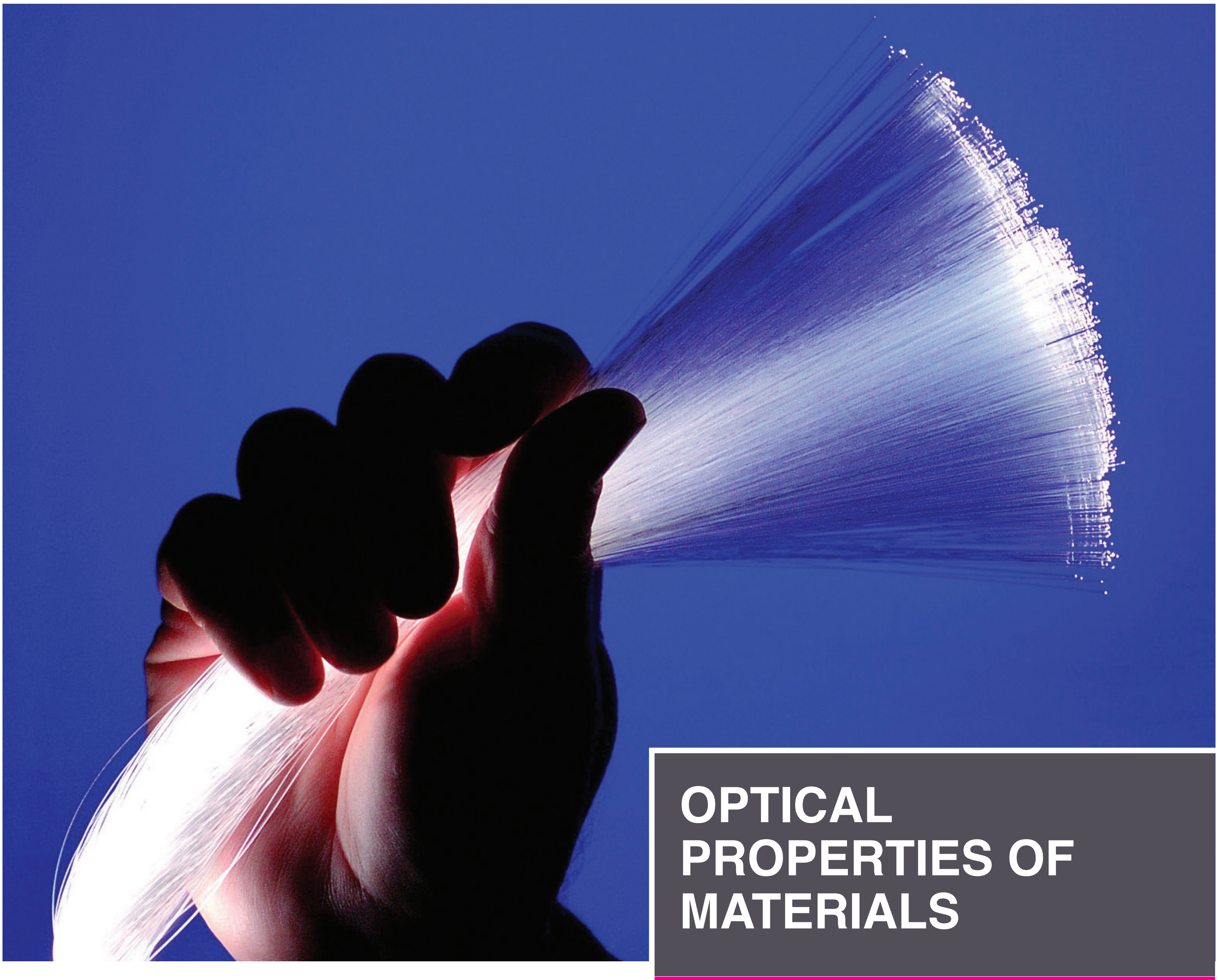

OPTICAL PROPERTIES OF MATERIALS

TEACHERS' MANUAL

ADAPTED VERSION

MATERIALS SCIENCE PROJECT

UNIVERSITY-SCHOOL PARTNERSHIPS FOR THE DESIGN AND IMPLEMENTATION OF RESEARCH-BASED ICT-ENHANCED MODULES ON MATERIAL PROPERTIES

SPECIFIC SUPPORT ACTIONS

FP6: SCIENCE AND SOCIETY: SCIENCE AND EDUCATION

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OPTICAL PROPERTIES OF MATERIALS

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CONTENTS

A: INTRODUCTION

A. INTRODUCTION

The Teaching Learning Sequence in Optical Properties of Materials has been originally designed and developed by the Working Group in Naples University in the context of the Materials Science Project. The Working Group in Aristotle University of Thessaloniki has transferred and adapted the initial Teaching Learning Sequence in the Greek context and specifically for the third form of the compulsory secondary school where optics is currently taught.

The initial version is based on hands on and ICT activities as well as on a combination of technological and scientific themes related to optical phenomena aiming at engaging students in an inquiry approach to science and enhancing their interest about science. Overall the Greek Working Group considered that this Teaching Learning Sequence is in principle applicable in the Greek context, it contains innovations and there are certain differences from the existing treatment of optics in Greek schools. In this context several core elements of the initial version as well as activities were kept as originally designed. Yet certain changes in the structure, concepts and activities were necessary in order to enrich the sequence and make adaptations for teaching to the Greek secondary school.

We would like to acknowledge the cooperation and the fruitful exchanges we had with the Local Working Group in Naples in working with them for making feasible this project which provided us with new and rewarding insights on the complicated issues involved in the transfer of a well designed didactical artefact. The contribution of Prof Martine Meheuet who acted as external expert was also valuable.

Apart from the teachers and researchers who are referred to the author's page without whom this project would not be feasible I would like to thank Sinan Yakup, Embluk Tayfun and Kapza Giouner, students of the Special Teaching Academy in Thessaloniki and Dafni Drakaki for handling data. Particularly I would like to thank Eleana Dalagdi for her continue work and contribution in the running of this project.

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B: DESCRIPTION AND ANALYSIS OF TEACHING AND LEARNING ACTIVITIES

B: DESCRIPTION AND ANALYSIS OF TEACHING AND LEARNING ACTIVITIES

UNIT 0: HOW DO WE SEE?

Learning objectives:

- To clarify the conditions under which one can see objects around us.
- To model how we can see.
- To clarify that models are abstracts or simplifications of the real world in order to represent, explain or predict phenomena.

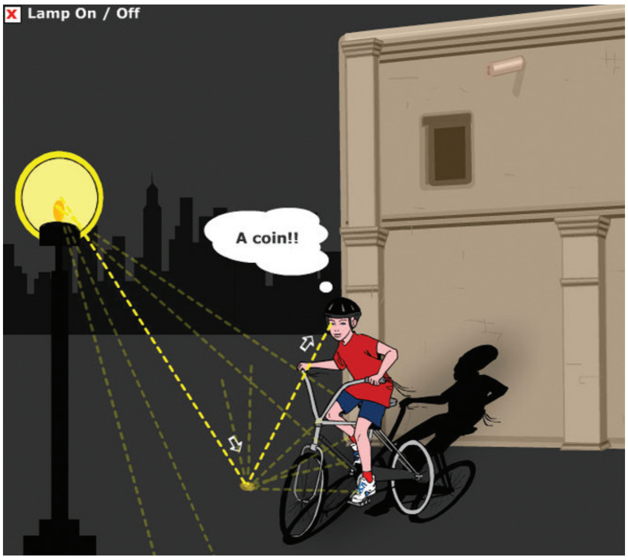
Duration: About 1 hour

ACTIVITIES 0.1. AND 0.2.

Preliminary simple observations allow for understand that:

- We see because some light arrives at our eye, which is the apparatus for detecting visible light.
- We see light emitted by a light source or light diffused by objects. The first is named “direct light” and the latter “diffused light”.
- We see because there are material particles that diffuse the light. In the activities with the torch pointing at the wall through air one sees only a spot on the wall, while if some particles are added in air, as smoke or chalk dust, one can see the light path.
- Smoke particles or chalk dust act as light diffusion centers and thus allow “seeing” the path of the light beam.
- It is part of common experience that sometimes one can see light beams entering through the window’s shadows.

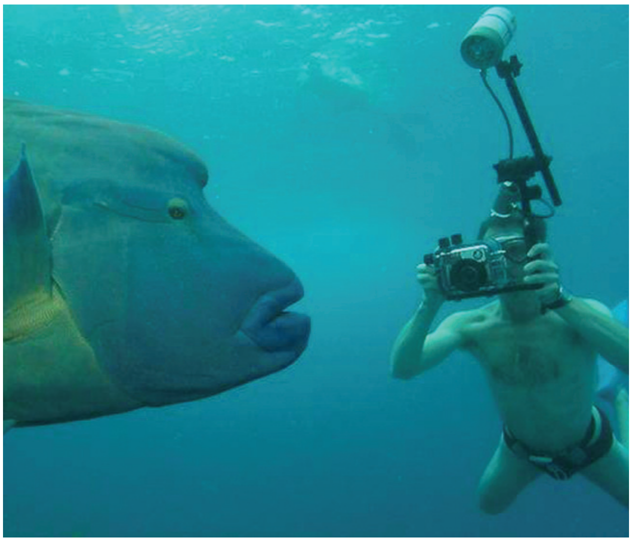
ACTIVITIES 0.3.

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
How we see Watch on the projection screen for the moment when the biker is able to see the coin. What precisely happens that enables him to see the coin? 	These activities attempt to create a model of how we see with the use of optic ray. Students are encouraged to observe the way light travels and that we use a single optic ray to interpret the phenomenon. Indicative Questions: • How is represented the light around the bulb? • Which of the beams of light are used to explain the phenomenon? • Does this respond to reality? • In what does this help us?

With the use of the applet the students are expected to realize that the models are an abstraction or simplification of reality in order to interpret the behavior of light. There is also made a first attempt to introduce the model of sight and their identification with the visual beam that students have observed in previous activities. This constitutes the first step of process which introduced in order to bridge model with reality. In this case light beam and optic ray are coincided in order to interpret the phenomena.

ACTIVITIES 0.4.

These activities aim at understanding that in order to be able to see, both the object and the observer (the eye) must be in a (at least partially) transparent medium.



These activities refer to how we can see through the water. While the students watch the first two images they realize that in order to see through the water the existence of light is required, just as it is in the air. In the first picture the diver is near the surface where there is enough natural light while in the second case the light does not reach the sea floor because of the depth, so the diver uses artificial light. In both cases the water is clean enough and the diver can see in contrast to the third photo where the water is not clean so he cannot see.

These observations allow for understand that:

- Also in water it is possible to see the light path if the water is not so "clean". Adding few milk drops allows for make the light path visible. The mechanism is the same as that for the dust particles or smoke in air.
- Even in distilled water one may see a feeble light path because there are diffusion centers, but fewer than in "dirty" water or tab water.

Conclusions

Activities 0.1 and 0.2 allow concluding that: we see light sources or objects that diffuse the light of some source.

Activities 0.3 allow concluding that models are abstraction of the real word in order to represent, explain or predict phenomena.

Activities 0.4 allow to conclude that: we see because diffuse (reflected) light passes through a transparent medium before entering our eye.

UNIT 1: WHAT ARE OPTICAL FIBERS

Learning objectives:

- Optical fibers allow for guide the light and transmit signal.

After introducing the "Scenario", about the FLAG network, the disaster that occurred when it was interrupted, leaving many countries unable to be connected, one may introduce this activity saying that: *"In the articles you read many times the word "optical fibers" has been mentioned. The systems that allow far-distance connections for signal transmission are based on optical fibers. They allow for transfer light at very large distances, without appreciable attenuations…We would like to know how this can be done and what we have to know about optical fibers in order to "design" them.*

Questions as:

Have you ever heard about optical fibers? Do you have an idea on how they are made? Have you ever seen them? Can trigger the activity and introduce the first example of optical fibers that may be familiar to students: optical lamps.

"Likely you have seen those interesting lamps that seem to be made of strings, sometimes also used for Christmas decorations. A light spot appears only at the end of the "string"…[1,2]

Recommended setting

Four-five students group performing the same experiment

Materials (for each group)

- Semitransparent, rubber or plastic tube (diameter 5-10 mm)
- Optical fiber
- Optical fiber lamps
- LED
- Fishing-lines
- Small torch bulb
- Battery 4.5 V
- Black cardboard or tissue (as screen)
- Black tape

Duration: about 1 hour and half

Didactical Notes

QUESTION 1.1.1.: OPTICAL FIBER LAMP

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Optical fiber lamp In order to understand the functioning of an optical fiber lamp, one can put together a number of optical fibers and find out that a LED is present at the lamp's base. Take a bundle of optical fibers and connect one extremity of the bundle to the light bulb. So, you have made an optical fiber lamp. Usually, LEDs of different colors light the common optical fiber lamps.	You may call attention on the fact that the path of light may be very strange, if you knot the wire and observe that nothing changes

1. *"In the ancient Egypt, the slaves that built tombs or pyramids needed to light long curved tunnels. To solve this problem the builders used a series of copper mirrors placed in such a way that the sun light, by multiple reflections, lighted the tunnels. However, the set of metal mirrors was not a handy system also because of the attenuation of light intensity. Nowadays, there are telecommunication systems that guide the light along transoceanic distances. Obviously, it could not be realized by using a mirror system! Such systems, which allow, for instance, making a call from New York to Tokyo without suffering any sensible delay, are based on the propagation of laser light in optical fibers. Let's try to understand how an optical fiber works."*

2. *In order to open the discussion, it can be useful to start from another issue connected, but different, and belonging to commonsense knowledge: Is it possible to bound the lighted region of space, given a specific light source? For instance, in everyday life, the need for a proper lighting to read or write calls for the use of a lampshade or any other device that can reduce the solid angle of emission of the light source at our disposal. A stimulating question can be: Which everyday objects, at home and outdoors, do you know that allow to bound the lighted region of space for a given light source?*

There are optical fibers with rough surfaces and ends. In such a case you may see light also in all the rough part of the fibers used to make the lamp. One may obtain this effect by removing part of the fiber's cladding. This is an indication that the fiber has an external part that plays an important role as far as light transmission is concerned, as we shall explore later.

QUESTION 1.1.2.: DRAWING THE LIGHT PATH

ACTIVITY DESCRIPTION	OPERATIVE SUGGESTIONS
Make a drawing of how you think light travels in each of the following cases: 	We draw students' attention to particular path of light inside optical fiber. We prompt students to draw the pathway of light using optic rays and to explain how they think light travels in each of the different cases e.g. to optical fiber lamp and the bulb.

The optical fibers can divert the light from the rectilinear diffusion. The students during a preceding activity coincided light beam with optic ray. The drawing of the pathway of light is considering as an application of ray model on unusual condition in which firstly model fails. Students are expected to give some preliminary explanations why this is happening. With this activity students may ascertain the limitations of scientific models e.g. the ray model that have been used so far. The debate may be about whether: *"Can the ray model explain what is happening and fiber optics guide light?"*

QUESTIONS 1.1.3. – 1.1.5.: OPTICAL FIBERS CAN GUIDE LIGHT

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Place an optical fiber straight on the table, a piece of black cardboard or tissue (as screen) at one end of the fiber and a small torch bulb at the other end. Light the torch and describe what you observe on the screen. Curve the fiber gradually and observe what is happening with the light spot on screen.	Optical fibers of different diameters can be used. While one student bends the fiber, another takes care of the contact between bulb and fiber.

When the optical fibers bent gradually, the light spot keeps its intensity. When the fiber breaks, the end of the fiber is still lighted. This makes plausible to infer that the optical fiber is a guide of light. Help your students to observe that no light passes through the outer surface of the fiber, i.e. what happens inside the fiber is not visible. One can stimulate questions about the material whose the fiber is made: *"It is transparent? Is the fiber made of glass? Can we bend a piece of glass?"*

QUESTION 1.1.6.: RUBBER TUBES AND TRANSPARENT PLASTIC WIRES

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Rubber tube Arrange the rubber tube straight on the table. Connect one end of the tube to a light bulb by means of the black tape. Place the black screen about 2-3 cm from the other tube end. Light the bulb by powering it with the battery (4.5 V). Curve the tube using a thin wire loop placed almost at the free end of the tube Pull the loop gently so that the tube bends gradually.	Keep the tube on the table in a straight position. Tourniquets (length about 8 cm) can be used. Such tubes allow a good connection with small flashlights. Do the experiment in a darkened room. Alternatively, use any blackened box (cardboard or whatever) around the setup.
Transparent plastic wire The optical fiber experiment is repeated using a transparent plastic wire lighted at one end	Fishing-lines (length about 10 cm) can be used.

When the rubber tube is bent gradually, the light spot dims and finally disappears. This allows for infer that the rubber tube is not a good candidate for guiding the light. Help your students to observe also that some light entering goes out through its outer surface

Transparent plastic wire
The experiments with optical fibers could lead to believe that the optical properties of the fibers are due to their small thickness and to the solidness.

The experiment with the fishing-line helps the students to observe that the optical fibers evidently are not ordinary plastic wires but they are designed with some special material.

Encourage a comparison between the experiments with plastic wires or rubber transparent tubes and optical fibers. The way of bending the material is the same, but the result is different. The outer surface of the rubber tube is lighted, while that of the fiber is not. The fiber breaks, the rubber tube not. Moreover, call attention on the spots produces on the screen by the tube low intensity and blurred boundaries) and the fiber (high intensity and sharp boundaries).

If you try to scrape an optical fiber (sand paper is ok), you see that the light passes through the scraped surface. Thus, the coating (cladding) of the fiber surface is a crucial ingredient for its peculiar optical properties.

QUESTION 1.1.7.: SIGNAL TRANSMISSION

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
A couple of students hold a piece of optical fiber. One student lights one end of the fiber and the other students is in a place where he cannot see his fellow student (behind the door for example). The second student is asked to recognize what signals the first student sent him: long-short etc)	The best way to perform the experiment is to have the student who sends the signal to do so by creating an interruption of the light beam with a piece of cardboard.

The activity aims at making students aware that an optical fiber is a good candidate for transmitting signals. One may also introduce what “coding” signals means.

QUESTIONS 1.2.: FIBERS’ DESCRIPTION AND THEIR CHARACTERISTICS

At the end of these activities students should be able to claim that “optical fibers are pipes (not hollow) made of a transparent medium”.

These objects allow to: guide the light; transmit signals.

Main conclusions:

- By means of suitable devices it is possible to guide the light along curved paths and direct it towards zones unreachable or difficult to reach by rectilinear propagation of light.
- By means of optical fibers, it is possible to direct the light towards a precise spot and, at the same time, to bound the illuminated region of space, even if the fiber has been bended.
- Optical fibers are light pipes.
- Optical fibers allow us to transmit signals.

What next?

The students have been helped to become aware that the main property of an optical fiber is to guide the light. They have also made a nice optical fiber lamp. But up to now it is not known how the fiber works and which are the properties allowing the fiber to guide the light. To understand what happens inside a fiber, we need a guide of light where we can “see” how the light propagates.

UNIT 2: IS IT POSSIBLE TO GUIDE LIGHT

Learning objectives:

- To construct, in the school lab, a light guide,
- To observe that internal reflection is the basic principle that allows for guiding the light.

The core of the activity is an experiment showing that it is possible to guide the light with a water jet which thus is taken as a good candidate for studying the basics of how an optical fiber functions.

The law of rectilinear propagation can be stated; observation of what happens at the interface between two media is also performed. This activity can be introduced by saying:
"Back in 1841 in a classroom of Geneva University in Switzerland, the physicist Daniel Colladon, observed by chance and for the first time that the light travelling in a water jet was guided within the jet. We'll reproduce that experiment using a techno-object not available at that time, namely a laser pointer. We'll observe carefully that "strange effect".

Recommended setting
Four-five student groups performing the same experiment

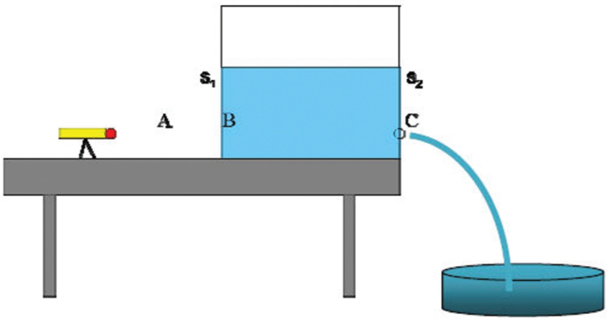
Materials

- A transparent container (about 30 cm length; 18 cm height; 16 cm depth; e.g. a low-cost plastic aquarium easily found in a pet shop)
- Low-cost laser pointer
- Support for the laser (clothes peg is OK)
- Tap water
- Black paper or fabric as screen
- Something to dry spilled water
- Incense candle (to make some smoke)

Duration: about 1 hour

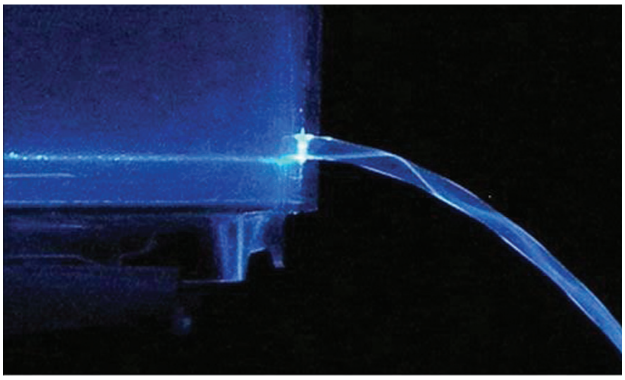
Didactical Notes

QUESTION 2.1.: PREDICTION

ACTIVITY DESCRIPTION	OPERATIVE SUGGESTIONS
The figure shows the experimental setup. Draw the path followed by the laser beam from its source (the pointer) to the basin that collects the water. 	This activity consist the first stage of the POE format which is used in the experiment. Students freely prompt to predict what will happen and to justify their answers.

This activity constitutes the second step of modeling process introduced in order students coincide ray model with laser beam which constitute a specialized condition of light propagation (monochromatic radiation) using in order to modeling the rectilinear propagation of light in homogeneous materials in most textbooks. Students prompt to draw with the use of ray model and justify the way in which light travels first on air and then inside water. This step is attempted to explore and elicit students' ideas adapted a more constructivist approach of learning sequence.

QUESTION 2.2.1.: EXPERIMENTATION

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Drill a small hole (about 5-6 mm diameter) in one of the small faces of the aquarium, about 3-4 cm from the bottom and close it with some tape. Use a drill point to get a hole with rather regular contour. Fill the aquarium with tap water up to about 10-15 cm height. Open the hole and use some container to collect the water coming out as a parabolic shot. The laser pointer is placed on its support near the aquarium face opposite the hole. The laser beam is horizontal, parallel to the table plane and lined with the hole. To better see both the laser beam and its path in the water, the classroom is darkened or the whole setup is in a box (any cardboard box is ok) whose walls are black (lined with black paper or fabric). 	To better see the laser beam (especially when it is not much powerful), it may be needed to work with "dirty" water, i.e. water with some chalk powder or "dirty" air i.e. air polluted with some hair spray or cigarette smoke. The students must stand laterally with respect to the laser beam, in order to avoid any direct view of the laser light. To allow all students see the details of the laser light beam path in the water shot, it may be convenient to give each of them a printout of a digital photo of the lighted water shot, done previously by the teacher.

This experiment, easily performed in class, is an appropriate emblematic example to help students understand under which conditions the light can be "guided".

Once the experiment has been done, the teacher calls attention on the path followed by the laser beam: firstly a rectilinear path (segments AB and BC) in a homogenous material (air then water); secondly the path within a zone where there is an interface between two different materials with different optical properties.

Observation and analysis of these two types of paths allow us to introduce two notions:

- *Homogeneous and inhomogeneous material*
- *Interface between two different materials and to check the Law of rectilinear propagation of light, when it moves in a homogenous material*

QUESTION 2.2.2.

It is useful to distribute a copy of the picture of the illuminated water jet for each group of students.

Go back to the experiment and ask to observe very carefully the water shot and the internal reflections in the water. What is more intriguing is the propagation of light in the shot. It has "guided" the laser beam. This property reminds what has already been observed in the optical fiber, but with a crucial difference. In the water shot the light is guided and its path is seen because of some light diffused by impurities always present in the water (dust or similar stuff). In the case of the fiber we do not see the path of the light. One may say that "the fiber traps the light". If it were trapped also in the water jet, this would mean that no light escapes from the jet and no beam would reach our eyes, producing no images of the internal reflection zig zags (one can here recall briefly what studied about vision and diffused light).

Looking carefully at the water jet one notices that light “bounces” at the interface water-air and one can “see” internal reflection of light, therefore the water shot can be thought, with good approximation, as a curved cylinder full of water whose walls (the lateral surface) are made of air. It is important, from a didactical viewpoint to point out the air-water sequence encountered by the light along its path. Recall the results of the curved fiber experiment. Since here the analogous result of guiding a light beam along a curved path, it is reasonable and plausible the assumption that what has been observed in the water shot is analogous to what happens in the fiber.

The fiber’s material is yet unknown, here the jet material is known: water surrounded by air.

Main Conclusions

First observations of a special *light guide* allow us to say that it is made of two different materials and an interface between them and that light is reflected at the boundaries between the two materials.

(If possible, it would be useful to anticipate the idea that a fiber should be made of a material surrounded by a different one, similarly to water and air, in the water shot experiment. This can help the comprehension of the basic of how a fiber functions: the internal total reflection on the interface between the two fiber materials (later called core e cladding)).

This activity has also addressed some topics thought in almost all basic physics courses: *the law of rectilinear propagation of light, homogeneous materials, interfaces between two diverse media.*

A medium is homogeneous when its properties are the same everywhere within the medium.

From the experiments we conclude that the laser light paths in an homogeneous medium are straight lines. Such a result holds every time light travels in an homogeneous medium.

This is known as the first law of the geometrical optics. Interfaces: the surface dividing two uniform (homogeneous) media is called “interface” or boundary. For instance, the flat surface of the table is the interface between wood (of which the table is made up) and the air. The water surface in the tank is the interface between water and air.

What next?

In the performed experiment the students have observed a light guide where the light path is visible. It is appropriate to explore why, when ad under which conditions the light does not travel a rectilinear path and when it bends as in the light guide.

UNIT 3: OBSERVING THE LIGHT PATH

Learning objectives:
- To observe situations where light deviates from its rectilinear path.
- Refraction and reflection.

One may go back to the original problematic envisaged in the “Scenario” and recall that one main aim was that of designing a light guide. This activity can be introduced by saying:
“We have observed the water jet gushing from the hole in the tank. In the jet, the light follows kind of zig-zag trajectory. We perform some measurement aimed at understanding why this can occur. In this activity we will set up a suitable situation to this aim”

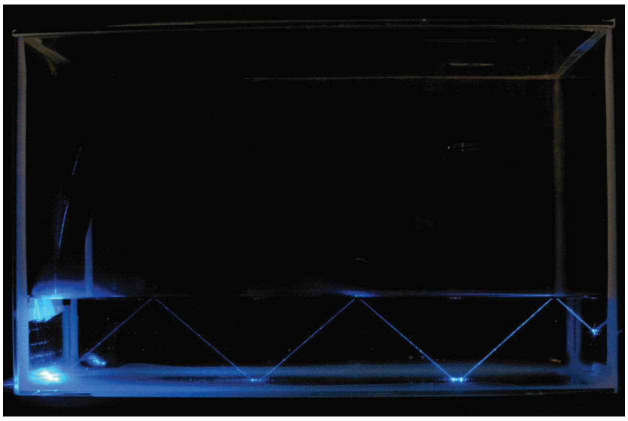
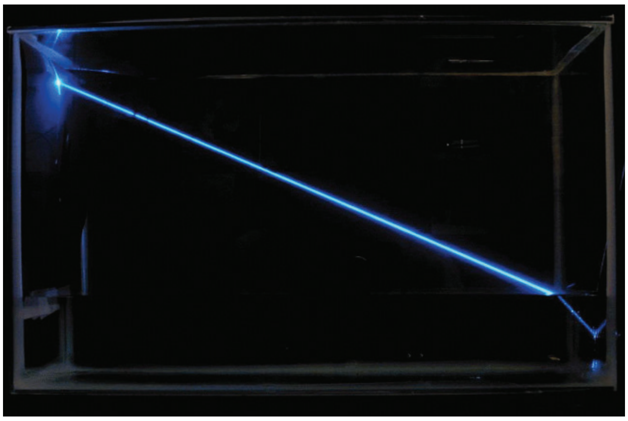
Recommended setting
Four-five students groups performing the same experiment

Materials
- A transparent container (about 40 cm length; 20 cm height; 16 cm depth)
- Low-cost laser pointer
- Tap water
- Incense candle (to make some smoke)

Duration: about 1 hour

Didactical Notes

QUESTIONS 3.1.: HITTING THE HOLE C WITH THE LASER.

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Fill the tank with water (about half way) and introduce smoke with the incense candle in the air above the water. Place a transparent cover on top of the tank. The hole C can be hit either orienting the laser pointer downwards, so that light goes through air first and then through water, or vice versa orienting the laser upwards from water to air. When the laser inclination is changed, one may observe refraction, reflection and also total internal reflection, if the light hits the water first. In this latter case one observes reflected and refracted beams and it is possible also to notice that, at a certain entrance angle of the laser beam, the refracted beam disappears and total internal reflection takes place. 	To better see the laser beam (especially when it is not very powerful), it may be needed to work with “dirty” water, i.e. water with some milk drops. The incense candle allows to introduce easily smoke in the air above the water. Once this is done, you should close the tank with the cover in order also to avoid too much smoke to fill the air of the lab. The table where you place the water tank should be perfectly horizontal. The students must stand laterally with respect to the laser beam, in order to avoid any direct view of the laser light. 

One may focus students' attention on the role of the interface water-air or air-water. Water acts as a reflecting surface (recall students' experience about mirrors).

This experiment allows for seeing, (e.g in the figure on the right) in many situations both the reflected and refracted beam and therefore allows to address a common difficulty induced in the schematic representations used in geometrical optics that the reflected and refracted beams are always present at the same time, but they can have different brightness. Observe also that this condition ceases when the limit angle is reached and the refracted beam disappears.

Further observations and questions:

- The brightness of the reflected and refracted beams is different. How does this depend on the amount of diffusing particles?
- Light is attenuated as it proceeds in the water, by multiple internal reflections.

  The latter observations allow us to gather information about the role of the bulk.

  Looking carefully at the pictures the light is also attenuated at the water surface, and also very much at the glass surface on the bottom of the tank. These observations will be reconsidered later.

Main Conclusions

When light hits at the interface deviates from its rectilinear path. One can observe, in such cases incident, reflected and refracted beams, that are always present together, even with different brightness.

Light deviation through reflection and/or refraction may be useful to orient a light beam towards a specific point.

What next?

After having performed qualitative observations that allow for recognize regularities in the observed behaviors, we proceed with measures, that will be performed in a virtual environment.

UNIT 4: WHEN AND HOW DOES LIGHT DEVIATE? REFLECTION

Learning objectives:
- Introduction to measurements errors.
- The law of reflection (Snell's Law).

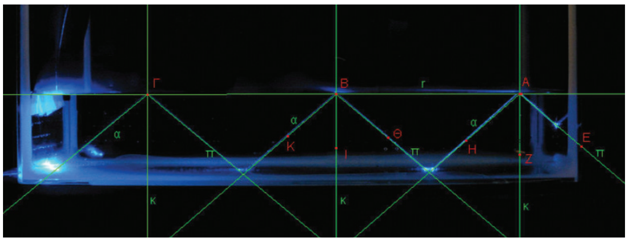
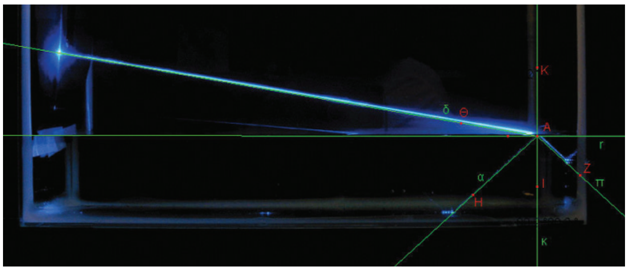
One may introduce this activity by saying:
"We will now focus on the light beam that is reflected at the surface water-air or vice versa..."

Recommended setting
1. Four-five students groups performing the same Cabrì activities
2. All class discussion about the values of angles determined by each group.
3. Law of reflection and critical angle discusses by teacher

Duration: about 1 hour

Didactical Notes

QUESTIONS 4.2. AND 4.3.: PHOTO AND CABRÌ CONSTRUCTION

CABRÌ PHOTO AND CONSTRUCTION	OPERATIVE SUGGESTIONS
Questions 4.2. Open the file "multiple_reflection.fig" 	This image is obtained when the laser beam enters the water tank from water to air and total internal reflection can take place. The concept of errors is introduced during the measurement. Therefore the comparison of the equality of the angles in the reflection is done by calculating the standard error.
Question 4.3. Open the file "reflection_refraction.fig" with the software Cabrì. 	The students may notice that the light beams in air and water have different intensities. They could in this case vary the width of the segments with the function "width" of the menu, to account for what they observe (see below)

One may notice that the reflected beams are not well visible while the spots at the water surface are very bright. This is also true for the spots at the bottom of the water tank.
An explanation for the different appearance of the light spots at the water-air interface and at the (bottom) interface water-glass is provided in "Teachers' Notes: Unit 6".

The bright spots at the top and at bottom may be well taken as the segments' extremes that model the light beams.

The values of the angles obtained by each group can be shared with the whole class. Here again one may focus students' attention on the differences between the physical phenomenon and the model.

Main conclusions
The Reflection Law of geometrical optics $\theta_i = \theta_r$

What next?
After having introduced measurements errors and law of reflection, we introduce the principle of least time or Fermat principle that will allow as interpreting refraction phenomena.

UNIT 5a: PRINCIPLE OF LEAST TIME OR FERMAT PRINCIPLE

Learning objectives:

- Principle of least time or Fermat principle
- Light travels into different materials with different speed

Recommended setting

1. Four-five students groups performing predictions and explanations
2. Principle of least time discusses by teacher

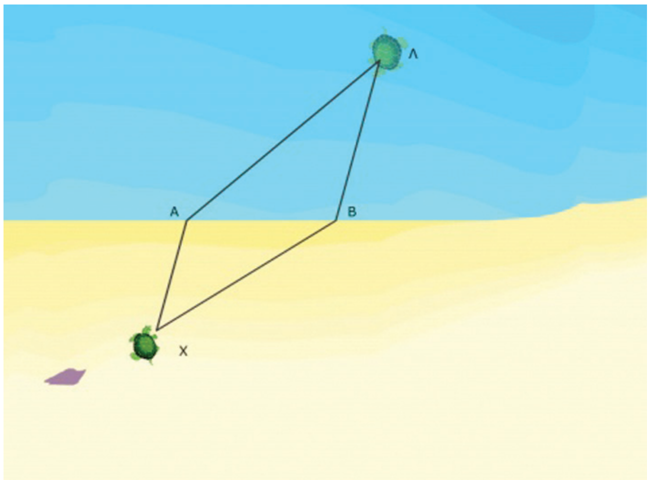
Duration: about 1 hour

Didactical Notes

QUESTION 5.0.1.

The turtle will follow the path:

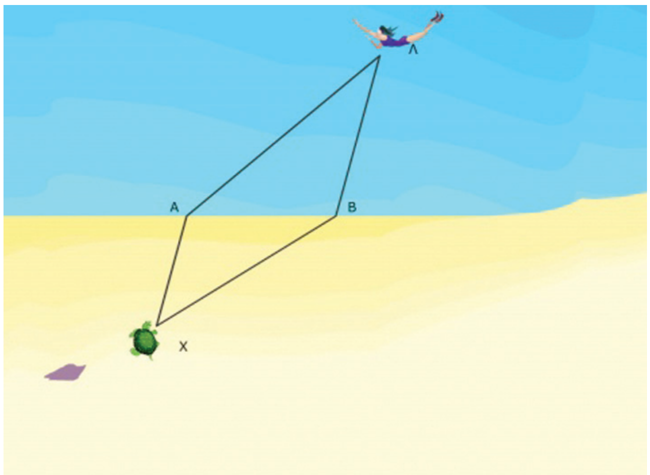
ΛAX ☐ ΛX ☐ ΛBX ☐



QUESTION 5.0.2.

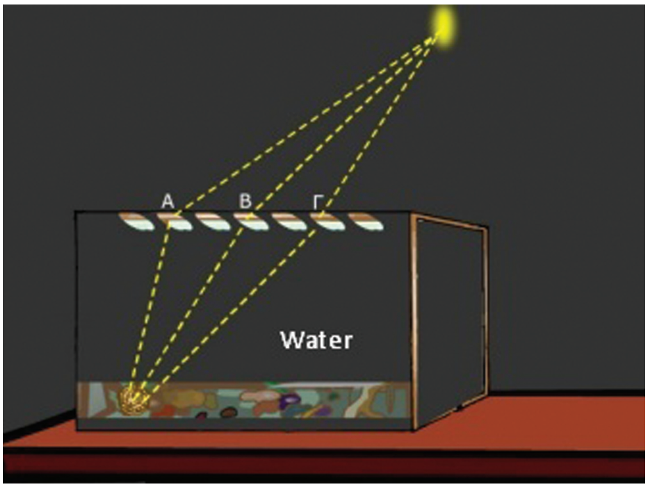
I would follow the path:

ΛAX ☐ ΛX ☐ ΛBX ☐



Students are asked to predict what will happen in two different cases. In the first case they have to choose which path the turtle will choose in order to go to its child, whereas in the second case which path will be chosen by the swimmer (us) for the same purpose. In both cases, the students are encouraged to justify their views and understand what factors influence their decision. With this way an initial investigation of Fermat's principle is made.

QUESTION 5.0.3. AND 5.0.4.



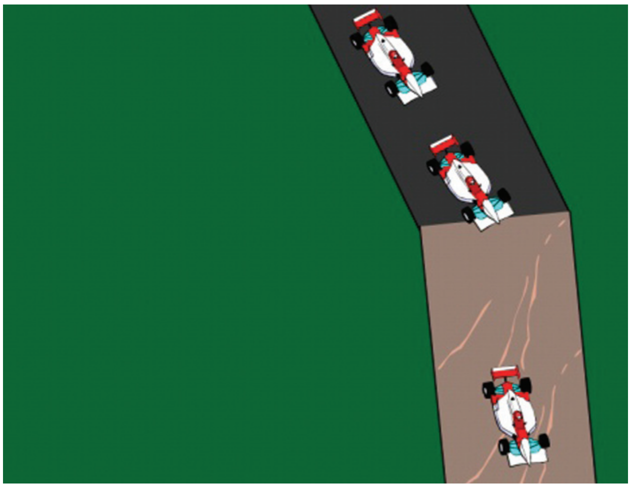
The light will follow the path through hole:

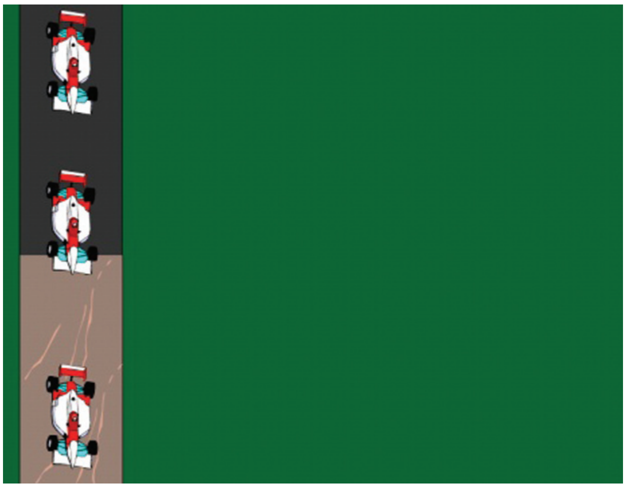
A ☐ B ☐ Γ ☐

This activity is a continuation of the previous one and students are asked to apply the above principle in the case of light transmission. The difference in speed of light in different materials is noted.

QUESTIONS 5.0.5. - 5.0.10.

In the picture you can see a car on the highway entering **sideways** into a muddy area.





Using a ratio it is attempted to interpret the phenomenon of diffraction. It may be noted that an optical beam is consisted of many parallel rays. The "Teaching with analogies" tactic is used. A ray of the beam is identical to the one wheel and one other ray to the other wheel of the car. The phenomenon of refraction construed according to the principle of minimum time and of different speeds in different materials that cause the car to change course. This ratio could also be a trigger for discussion of different models of light.

Main conclusions

- Light travels at different speeds in different materials.
- This attribute of the light may explain why the light refracted

What next?

Before going back to study the light guides, we must understand what happens to the refracted beam…

UNIT 5b: WHEN AND HOW DOES LIGHT DEVIATE? REFRACTION

Learning objectives:

- Study light behavior as it is refracted from a surface.
- Define the refraction index, formulate the refraction law.
- Determination of the critical angle for total internal reflection.

One may introduce this activity by saying:
"We have observed in the experiment what happens when the light beam hits the water surface propagating from air to water. Let's now focus on this light beam".

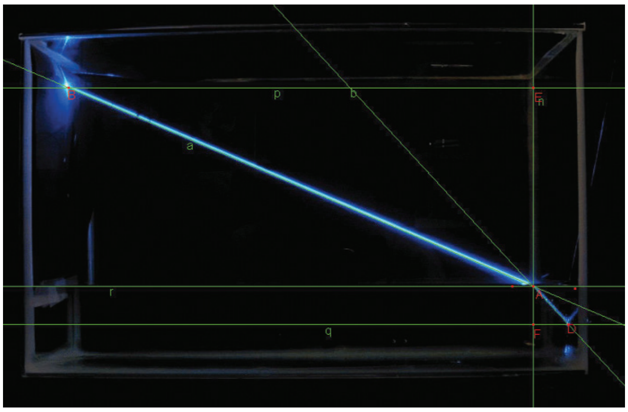
Recommended setting

1. Four-five students groups performing the same Cabrì activities.
2. All groups discussion of the obtained values for the refraction index.

Duration: about 2 hours

Didactical Notes

QUESTION 5.1.: PHOTO AND CABRÌ CONSTRUCTION

CABRÌ PHOTO AND CONSTRUCTION	OPERATIVE SUGGESTIONS
 The construction of the triangles is reported in the file "refraction_image.fig"	The students may notice that the light beams in air and water have different intensities. They could in this case vary the width of the segments with the function "width" of the menu, to account for what they observe (see below).

It is suggested that students identify the incidence and refraction angles and define the sine of the angle by means of the ratio cateto/ hypotenuse.

If different pictures of refraction are distributed among the groups, then each group can determine a value of the relative water/air refraction index. Sharing all values and discussing allows comparing the value they have obtained with the one indicated in tables of refraction index for common substances.

The ratio $\frac{BE}{AB}$ / $\frac{DF}{CD}$ = 1.33 is indicated thus as the relative water/air refraction index.

The ratio $\frac{BE}{AB}$ can be called "sine of the incident angle" (in the construction it is implicit that the angle is measured with respect to the normal to the water surface).

The ratio $\frac{DF}{CD}$ can be called "sine of the refracted angle" (in the construction it is implicit that the angle is measured with respect to the normal to the water surface).

Modeling light propagation phenomenon with the Cabrì construction

This activity is constitutes the third step of our modeling progress, bridging real to model. As the students become familiar that ray model represent light beams (or laser beams), they can notice that in Cabri construction many aspects of the real phenomenon are not represented: mainly the light beam is modeled as **"optic ray"** and all rays are represented by segments of the same width.

The different intensities of the beam in water and air should be noticed and (as suggested above in "Operative suggestions") marked in the Cabrì construction. A discussion of reasons for the **different intensities**, in relation with the bulk particles is strongly advised.

A discussion about such aspects allows us to further discuss the difference between **the phenomenon and its (abstract) representations.** The proposed construction namely digital photos imported in Cabrì in order to extended modeling of the observed phenomena, is a very straightforward way to do so.

QUESTION 5.1.: PHOTO AND CABRÌ CONSTRUCTION

CABRÌ APPLET SIMULATION	OPERATIVE SUGGESTIONS
Open the file "refraction_index.fig"	In order to vary the inclination of the laser beam one has to select the pointer in the menu. In order to vary the refraction index of medium 2 it is advisable to use the small arrows. In order to vary the water's height you must select (with the pointer) the point H and drag downwards or upwards. Even if the height of the liquid in the tank is reduced to a minimum value, it is impossible to reduce it to zero and thus there is always refraction.

Different measures of the ratio allow deducing that n_1/n_2 does not vary with the inclination angle of the laser beam (incident angle) nor with the height of the water in the tank, therefore

$$\frac{\sin(\alpha)}{\sin(\beta)} \equiv \frac{n_1}{n_2}$$

constant and n_1 and n_2 are constants that depend on the material.

A range of possible values for n_1 and n_2 is useful for the students to know.

QUESTION 5.3.: CRITICAL ANGLE

CABRÌ APPLET SIMULATION	OPERATIVE SUGGESTIONS
Open the file "critical_angle.fig" Let the refraction index of medium 1 be 1 and 1,33 the refraction index of medium 2. On the normal n' trace the semiray a that represents the entering beam. Rotate the semiray a until you don't see any more refracted rays in air. Measure the incidence θ_i and reflection θ_r angles of the laser beam on the interface water-air.	By rotating the semi-ray a which represents the incident beam it is possible to observe that at a certain angle the refracted beams disappear. This allows focusing on the particular angle (limit or critical angle) for which this is achieved.

When performing activities with the Cabrì applets it is wise to go back frequently to the experiment, in order to connect what the students are doing in this phase with what they have observed, and also explain that the use of the virtual environment of the simulation is a useful tool to perform measures. In this case one can measure the incident, reflected and refracted angles.

Students can work on photos (one for each group and different ones) where they can trace the incident, reflected and refracted rays. With the Cabrì construction each group can determine the relation between the incident, reflected and refracted angles.

The *Reflection Law* of geometrical optics can be formalized at the end of these activities. As a matter of fact, focusing on each pair of adjacent angles θi and θ_r allows to claim that $\theta_i = \theta_r$

Total internal reflection
The smallest angle for which there are no more refracted "rays" (or light beams in general) is called $\theta_i = \theta_L$ "limit, or critical angle".

The existence of a "critical" angle follows from Snell's law, when the ratio

$$\frac{\sin(\alpha)}{\sin(\beta)} = \frac{n_2}{n_1}$$

is greater than 1.

This can happen when light propagates from a medium that has larger refractive index to one with smaller refractive index. In our case from water (n_1 = 1,33) to air (n_2 = 1,00).

Since the refracted beam moves away from the perpendicular, at the value π/2, the refracted beam will cease and all the light is reflected. This phenomenon is called total internal reflection.

By Snell's law this happens for the incident angle $\theta_i = \theta_L$ = limit angle, such that
$n_1 \sin \theta_L = n_2 (\sin \pi/2 = 1)$ or
In our case θ_L = arcsin (1 / 1,33) = 48,75°.

Main Conclusions

- Light travels through a homogeneous medium (say medium 1) in a straight path. When the light reaches the boundary with a different medium (say medium 2) light, some light will be reflected on the boundary and some light will be transmitted into the medium 2. When light hits the boundary at a certain angle with respect to the normal to this boundary (in the previous experiment it was called α), the light path bends from the original direction, i.e., it follows a "new" direction characterized by an angle β with respect to the normal to the boundary. The transmitted light undergoes refraction.
- Law of Refraction of Geometric Optics: (Snell law, 1621) The angle α between the incident beam and the normal to the interface of media 1 and 2 and the angle β between the refracted beam and the normal are related by the following relation:
  $\sin\beta = \frac{\sin\alpha}{n_{12}}$
  ,where $n_{12}=n_1/n_2$ is a constant which is related to the optical properties of both media, 1 and 2.
- In the case of the experiment performed in activity 3, depends on water and air and is called refractive index of water relative to air. In the experiment, this constant should be about 1.33.

- The refracted beam in this case approaches the normal to the boundary.
- The definition of the critical angle for total internal reflection.

The possibilities offered by the use of the simulation applet allow us also to address the dependence of the refraction angle on the type of material, a topic not traditionally taught.

What next?
Going back to the water jet we will see that it is indeed total internal reflection the basic physics phenomenon that allows us to guide the light.

UNIT 6: HOW IS AN OPTICAL FIBER MADE? FIRST CLUES

Learning objectives: to become aware that in order to construct a light guide one must have a transparent medium surrounded by another transparent medium of lower refraction index.

One may introduce this activity by saying:
"Let's go back to all the experiments we performed up to this moment and look at the objects we have observed first and then investigated: optical fibers, rubber or plastic tubes and the water jet. Let's look again at the experiments with the water tank. All these experiments will serve to gather the clues which will allow us to understand a light guide's characteristics".

Recommended setting
Four-five students group work with pictures of the previous experiments, or the teacher may repeat the experiments.

Materials (for each group)
- Semitransparent, rubber or plastic tube (diameter 5-10 mm)
- Optical fiber
- Optical fiber lamps
- LED
- Fishing-lines
- Small torch bulb
- Battery 4.5 V
- Black cardboard or tissue (as screen)
- Black Tape
- Water tanks
- Laser pointer

Duration: about 1 hour

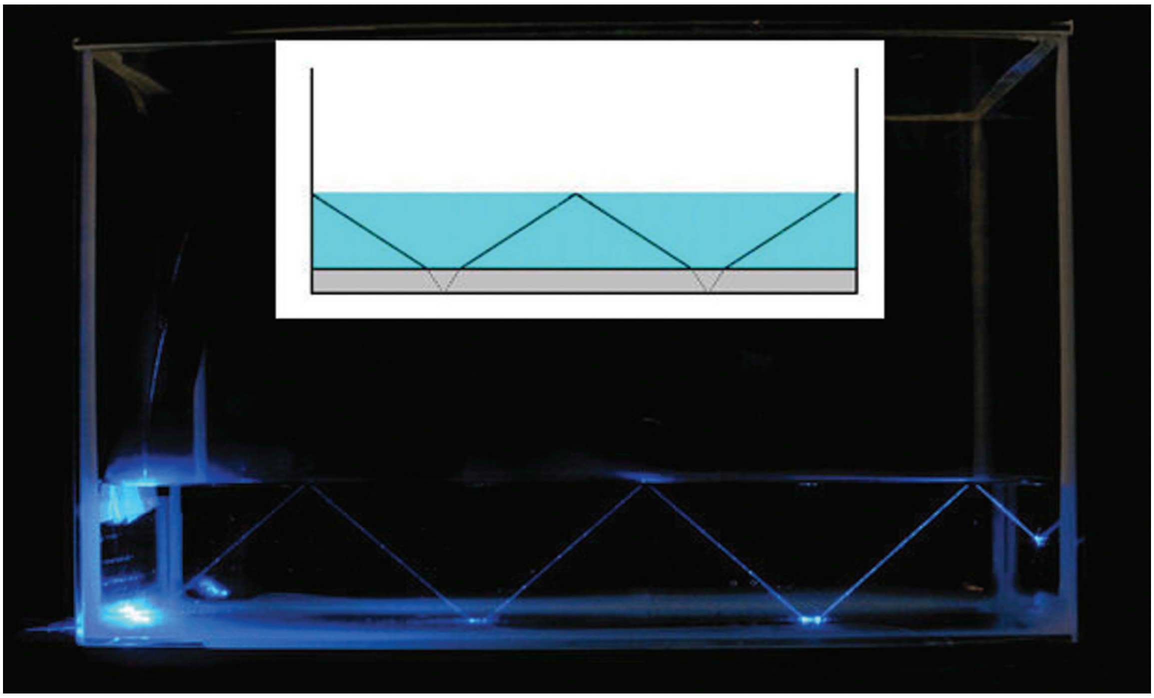
Didactical Notes

QUESTIONS 6.1.

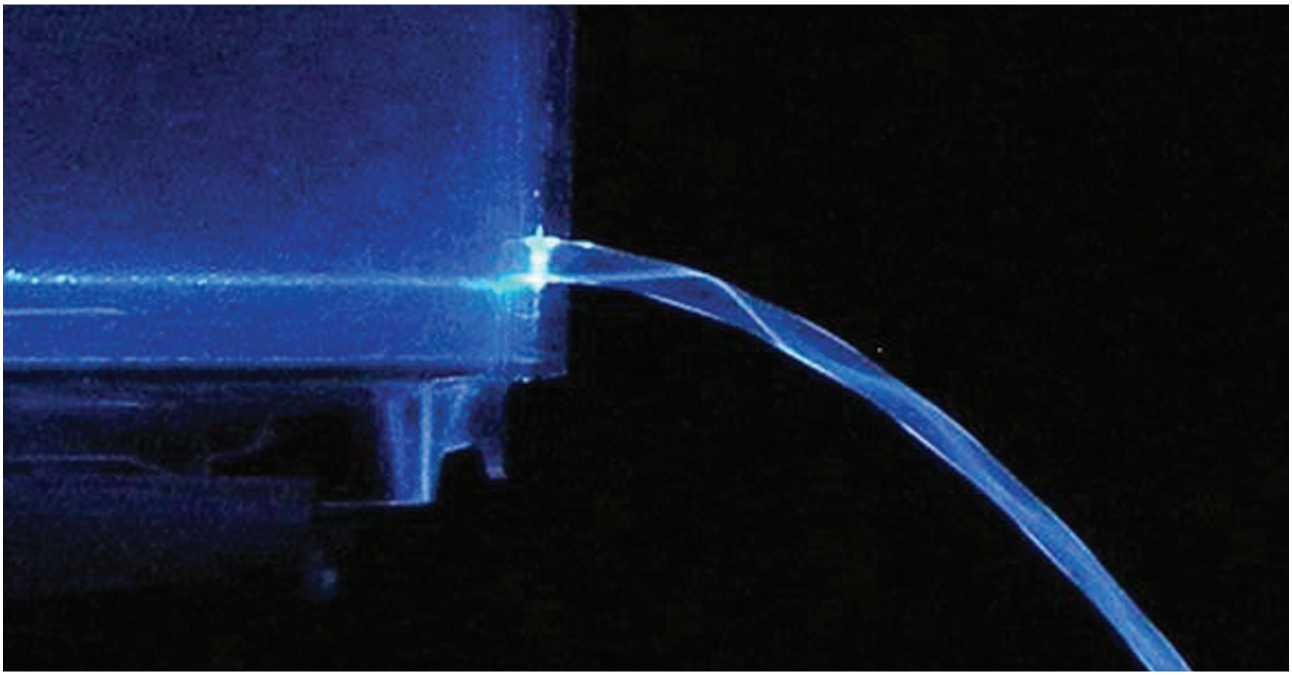
In *Experiment 1* of the water tank one observes that the interfaces are water-air (on top) and water-glass (on bottom).

At the upper interface, at the critical angle, there is total internal reflection. This is not true for the other interface water glass (at bottom) since light propagates from water (lower refraction index) to glass (greater refraction index) and thus the condition for total internal reflection does not hold.

A schematic representation of what happens at the lower surface, that takes care of the glass width is here represented.



This model well fits what one observes in the experiment where the light spots are very bright.



In *Experiment 2* the interfaces of the water jet are always water-air and the laser beam is undergoes total internal reflection, on both surfaces which *allows the light to bend along its path. The same happens in the optical fiber.*

One may thus conclude that a sandwich of two media, one with lower refraction index surrounded by another of greater refraction index, allows guiding the light through total reflections, if light is sent in the inner medium.

All the objects of the first activities (cfr. Worksheet and Notes 1) are re-examined, in order to synthesize the properties of a light guide.

The inner material is named “core” and the outer material is named “cladding”.

In the water jet the core is water and the cladding is air. All transparent tubes as glass plastic plexiglass are potentially light guides. Of course their lack of flexibility impairs the possibility to orient the light as it is done in the optical fiber.

Main conclusions

In worksheet and notes 1 we concluded that light guides are

a) *Transparent tubes (not hollow)*

Now we add more clues to construct an optical fiber, having understood that the main mechanism for guiding the light is total internal reflection. That is

b) *in order to guide the light one must have a transparent medium surrounded by another transparent medium of lower refraction index.*

When light is sent into the inner medium it undergoes total internal reflection at the interface between the two media.

c) we name “core” the inner material and cladding the outer material.

What next?

Let’s look for more clues... We want to construct an object that looks more like an optical fiber….

UNIT 7: DO WE WANT TO SEE THE LIGHT PATH IN THE FIBER?

Learning objectives:

- Attenuation of light as it travels in a medium.
- Transparency has to do with light attenuation.
- Transparent materials.
- How to make a material more transparent.
- Bulk effects: the role of diffusing particles, light absorption.
- Light attenuation in optical fibers due to surface effects: the interface core-cladding.

Recommended setting
Four-five students group work

Duration: about 1-2 hours

Didactical Notes

QUESTION 7.1.

Lets' go back to the optical fibers….

You may go back to the **Scenario** where different uses of the optical fibers where explored and compare with the water jet:

For what purposes could the water jet light guide be used for?
Which liquid would you choose then?
Could the water jet be suitable for transmitting signals?
What are the possible drawbacks?

POSSIBILITIES	DRAWBACKS
Water fountains	Not possible use for signal transmission due to mainly to **light attenuation**

We have investigated about an optical fiber's main characteristics and we have also seen that in an optical fiber we don't see the light travelling in the fibers' core. Do we want to see the light path? What advantages might this have? What drawbacks?..

To be able to see the light path, is an indication that light is attenuated (some of the emitted light enters the eye).

Where does **attenuation** come from?
Main factors that affect light attenuation **in an optical fiber** are related to **bulk** (as **in all materials**) **and also to surface properties.**

Bulk properties: relate to the nature of the core and of the cladding. It is true for all materials that intensity attenuation depends on the material's properties for a fixed radiation[3].

Surface properties relate to the nature of the core-cladding interface.

Since light in the optical fiber hits (is reflected) many times the interface core-cladding we can ask if these reflections affect light attenuation.
Does attenuation depend on the amount of matter that light encounters?

How does attenuation relate to color? What are possible effects of this?
Absorption can be addressed with the water jet colored liquids or recalling the common experience of warm black clothes exposed to light versus white clothes. The main effect produced by light absorption is warming.

What happens when there is (ideally), in a material, NO attenuation?
All the light that enters in a material comes out of it. We call "transparent" materials the ones that let the light pass through them without appreciable attenuation.

Which transparent materials do you know?
Observe also those materials that can be transparent with respect to some e.m. radiation and not to other, and that attenuation has to do with the interaction matter-radiation.

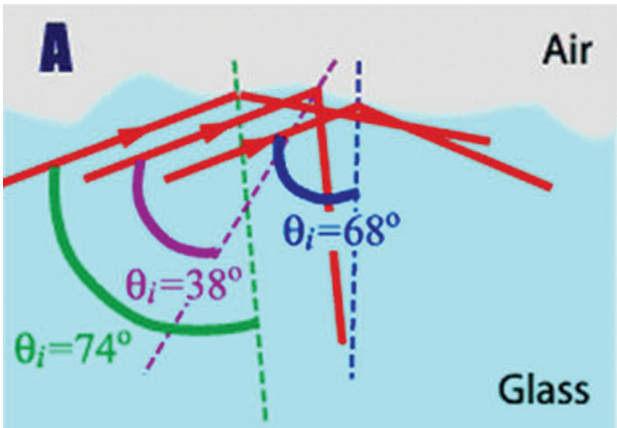
Attenuation is an important factor limiting the transmission of light across far distances.

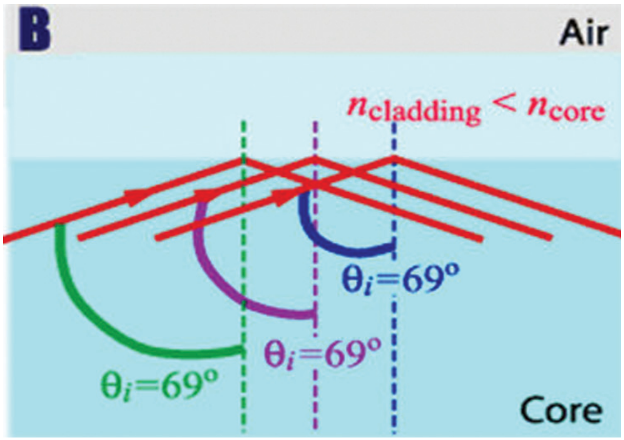
QUESTION 7.2.

When one scratches an end of a fiber (for example in the optical fiber lamp) one may see diffuse light, where the cladding has been removed. Since "to see the light means intensity reduction", students can understand that the core-cladding's interface properties are important in determining light attenuation.

One can become aware of the fact that the interface core-cladding must be straight and smooth, otherwise one observes diffuse reflection, as the scratched fiber shows.

The schema below allows us to understand the reasons for such behavior.





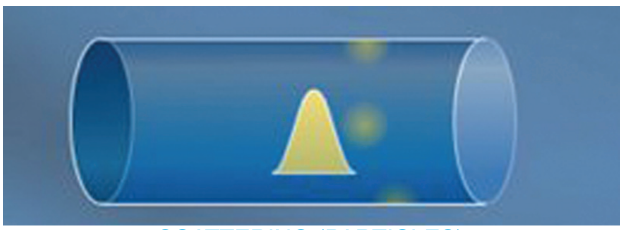
In figure A, where the surface of glass is rough, one may say that some rays that hit the surface could be not at the critical angle, while in figure B, they are alla parallel due to the smoothness of the surface.

When the interface core-cladding is rough light is no more trapped within the fiber's core and one sees diffuse light arriving at the eye.

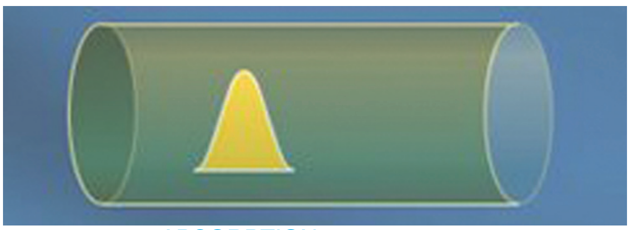
3. *The process of light transmission in an optical fiber is not 100% efficient: power leaving the fiber is less that that entering the fiber. Attenuation takes into account of this phenomenon. The picture below illustrates attenuation in a schematic way.*

SIGNAL ENTERING THE FIBER

SIGNAL AT THE FIBER'S EXIT



SCATTERING (PARTICLES)



ABSORPTION

Main conclusions

- Transparency means that light is not attenuated when it travels in a material.
- Scattering and absorption in the bulk are factors that determine light attenuation.
- Diffusion at a rough interface can affect loss of intensity.

In **optical fibers**, attenuation is the rate at which the signal light decreases in intensity. For this reason, glass fiber (a transparent material which has low attenuation) is used for long-distance fiber optic cables; plastic fiber has a higher attenuation and hence shorter range. The latter are used in clinical endoscopy.

C: EVALUATION TASKS

C: EVALUATION TASKS

PRE-TEST

NAME: ....

PART A

1. Two rays intersect when:

a) they have only one point in common. ☐

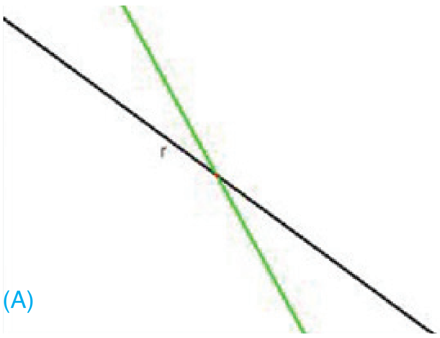
b) they have at least one point in common. ☐

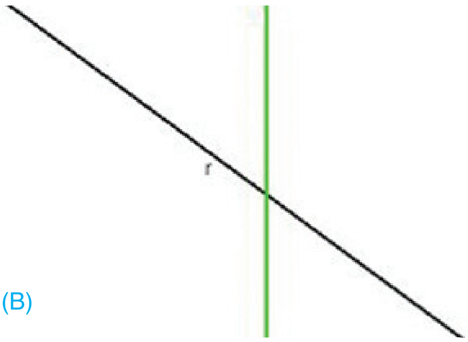
c) they don’t have any point in common. ☐

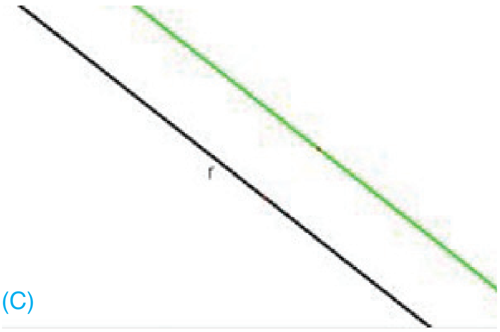
Choose the correct answer.

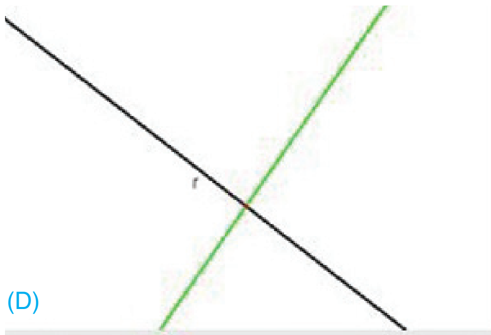
2. Given a ray ε, in which of the figures below is represented a ray that is:

	FIGURE (A)	FIGURE (B)	FIGURE (C)	FIGURE (D)
I. Cross with ε?				
II. Perpendicular to ε?				
III. Parallel to ε?				


(A)

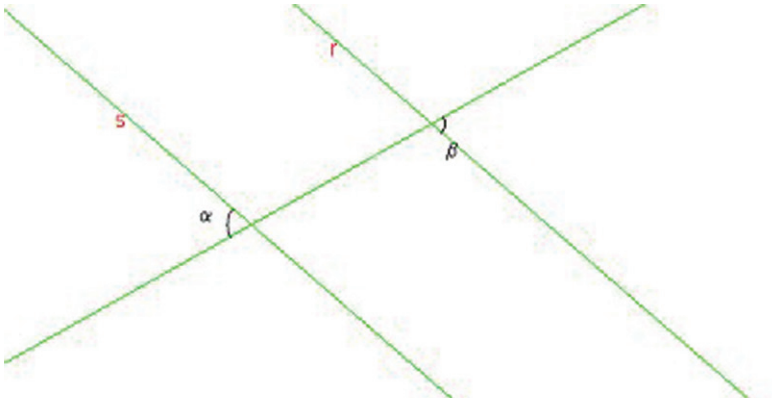

(B)


(C)


(D)

3. The rays r e s are parallel to each other, therefore the angles α and β:

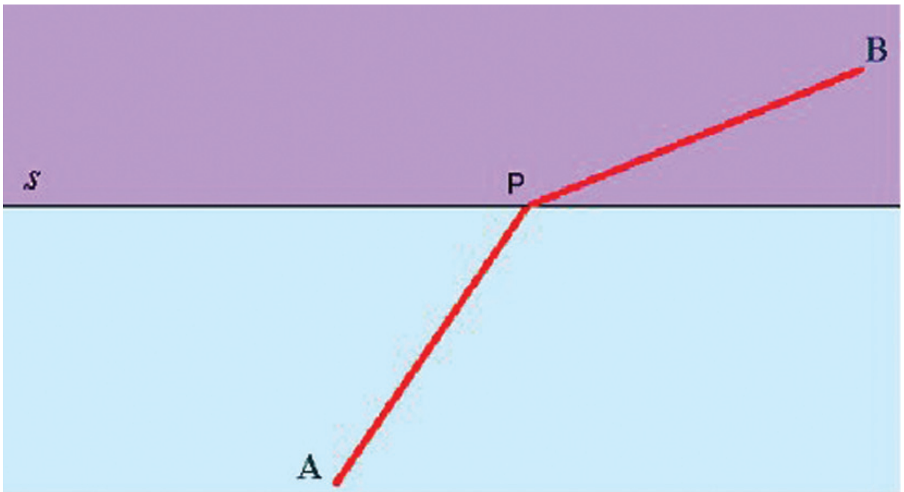
a) Are equal
b) Their sum is 90°
c) Their sum is 180°



Explain briefly

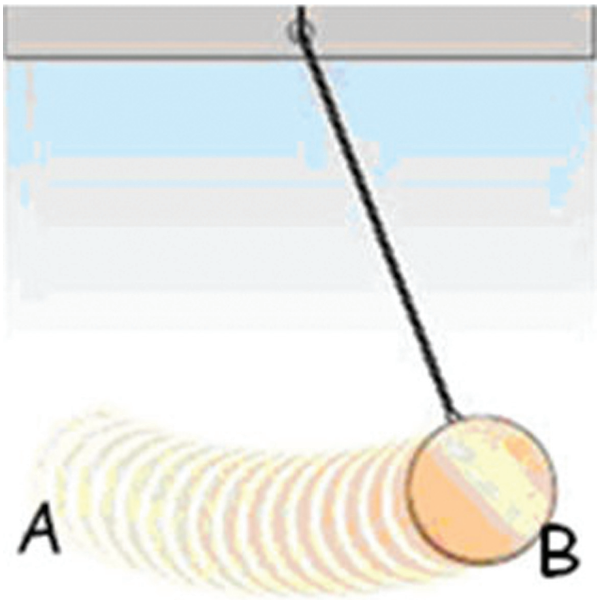
4. Trace the perpendicular to the ray s, and through point P. Trace counter- clockwise the angles that segments AP and PB form with such a perpendicular.

Which of the two angles is greater?



Explain briefly

5. **Suppose you have measured six times the time interval that is needed for the pendulum to make a complete oscillation. The six values are reported in the table.**



Measure	Period (s)
1	2,5
2	2,7
3	2,4
4	2,6
5	2,5
6	2,3

The mean value of such measurements is: ....

Explain briefly

....

....

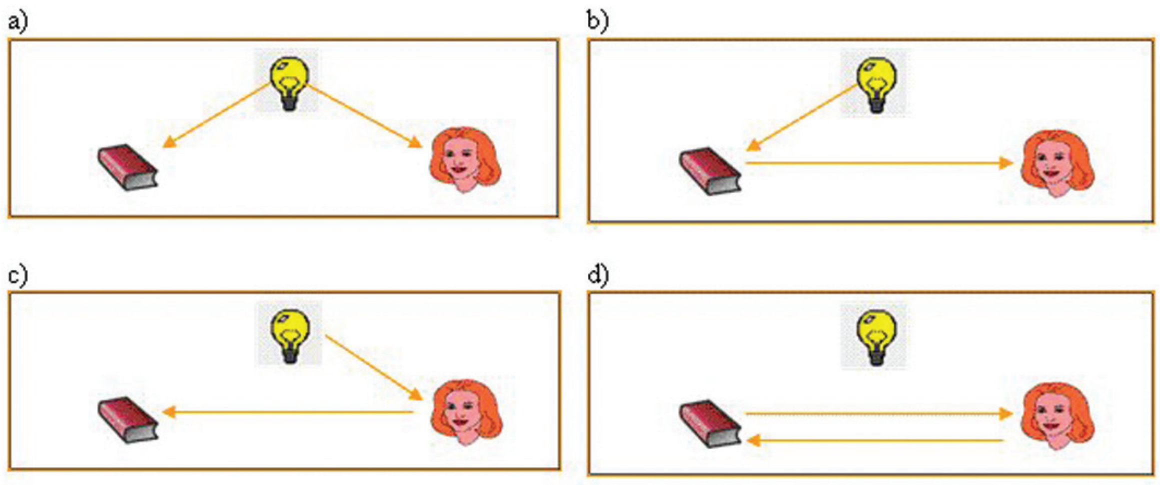
....

PART B

1. Is it possible to see in absolute darkness?

Explain your answer.

2. Which of the pictures below better represents the mechanism for which we see objects around us?



Explain briefly

3. **Look at the picture below. Why sometimes you can see light beams filtering from the clouds?**

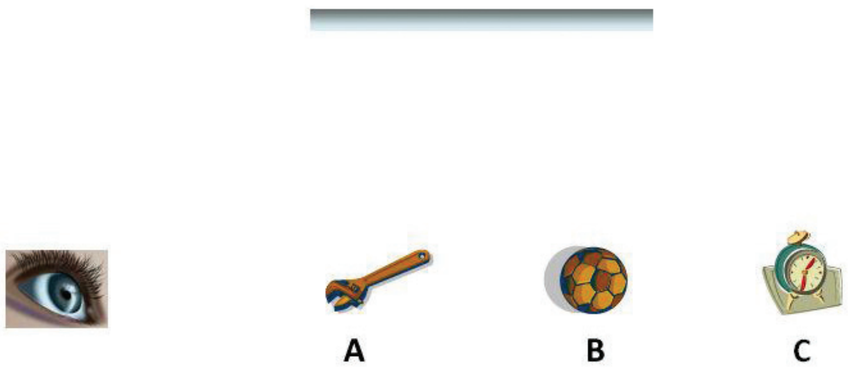
Explain briefly

....

....

....

4. **Which of the following objects the observer is able to see at the mirror?**



Justify your answer.

....

....

....

5. **What happens when light hits a still water surface? Choose the correct answer.**

(a) All the light comes back in the air. ☐

(b) Light will travel only in the water. ☐

(c) Some light will travel in water and some will come back in air. ☐

(d) All the light is captured by water. ☐

(e) We need more information about the nature of the water surface. ☐

6. **What do you know about optical fibers?**

....

....

....

....

7. **Explain why there is natural (from the sun) light inside this room right now?**

....

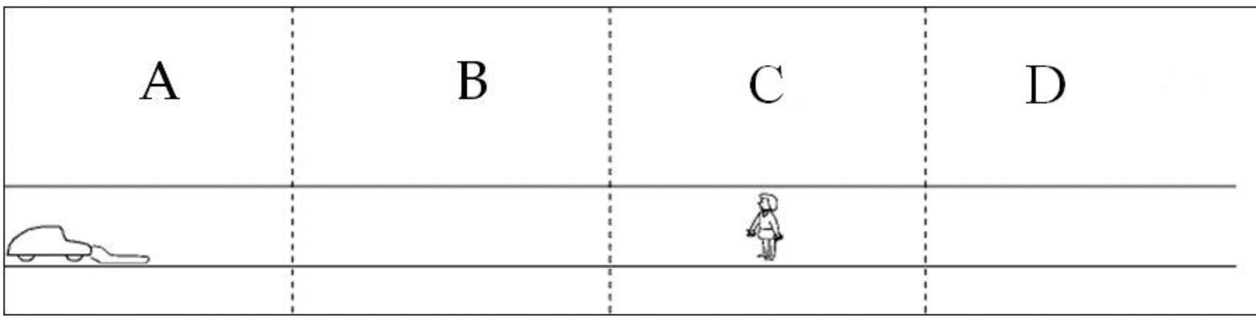
....

....

....

8. **On a clear sunny day, a car is standing parked on a straight, flat road and has its headlights on. A pedestrian, is standing in the road about 200m away from the car.**

Do you believe that it is able to see the headlights?
The illustration is divided into four sections. In which section is there light?



Explain your answer.

If it was a clear dark night what it will be happened?

9. What will happen if a narrow light beam of a headlight hit from air the quite surface of water? (Choose the correct answer)

(a) All the light is reflected and scattered in the air. ☐

(b) All the light is inserted in the water and scattered. ☐

(c) All the light is inserted in the water and incline from its path. ☐

(d) The light is partially reflected and partially inserted into the water and incline from its path. ☐

10. A fisherman sees the fish at lower depth in regard to the point in which actually is. The fish see the fisherman:

(a) at the same point in which they are actually is. ☐

(b) at lower depth in regard to point in which actually is. ☐

(c) at higher depth in regard to point in which actually is. ☐

Explain your answer.

RUBRICS

PRE-TEST

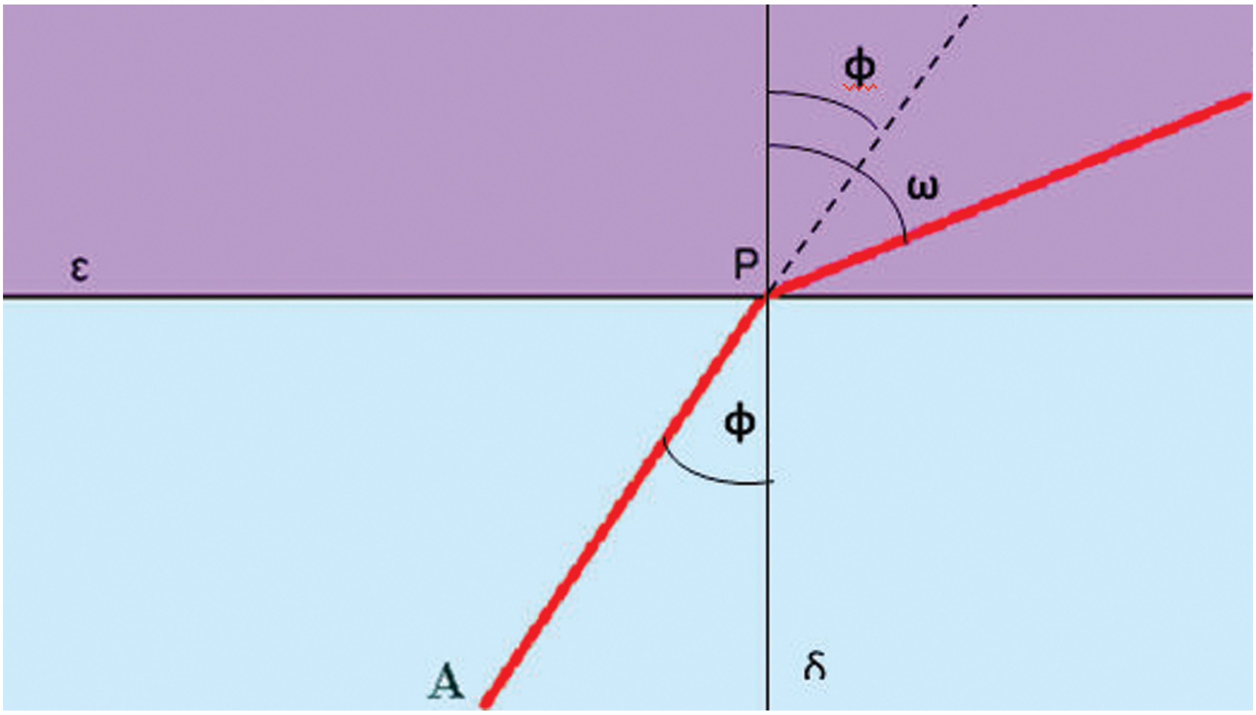
PART A

1. a) (1 point)
2. I) Cross with ε, figures a), b) and d) (0,5 point),

   II) Perpendicular to ε, figure d) (1 point),

   III) Parallel to ε, figure c) (0,5 point)
3. a) (point 1)
4. Angle formed by segment PB is greater than that of AP. (1 points)

   WITH REASONING (see the above figure) since φ = φ´, in that case ω > φ´ = φ (2 points)



5. Average value is 2,5 (1 point) or

   WITH REASONING according to the means' definition: 2,5+2,7+2,4+2,6+2,5+2,3 = 15, 15/6 = 2,5 (point 2).

PART B

1. Objects diffuse the light (that enters our eyes) that reaches them from a light source. If there is no such source no light can enter our eyes. (1 point)
2. Light source lightens up the object which reflects part of the light into our eyes. (1 point)
3. Light is scattered and diffused by vapor molecules near the clouds. (1 point)
4. He will see only B and C objects for which inclination angle is equal with reflection angle as light propagates from object to observer. (1,5 point)
5. c) (point 1)
6. Optical fibers are made by glass in order to transfer light at long distances without remarkable attenuation aiming to transmit signals or messages. (point 1)
7. Because objects and air bulk are diffuse the light from the sun which enters to room through multiple reflections. (point 1,5)
8. The pedestrian can see the headlights during the day because light propagates rectilinear until it absorbed or meet a non transparent obstacle. (point 0,5)

   The light will be at all sections. In the night it will be the same without sun of light reduce eye's sensitivity. (point 1)
9. c) Because the pathway of light which reaches to the fish changing its direction on water's surface and as a result the fish will see the fisherman at higher point that really is. (point 1,5)

POST-TEST

NAME: ....

11. Is it possible to see in absolute darkness?

Explain your answer.

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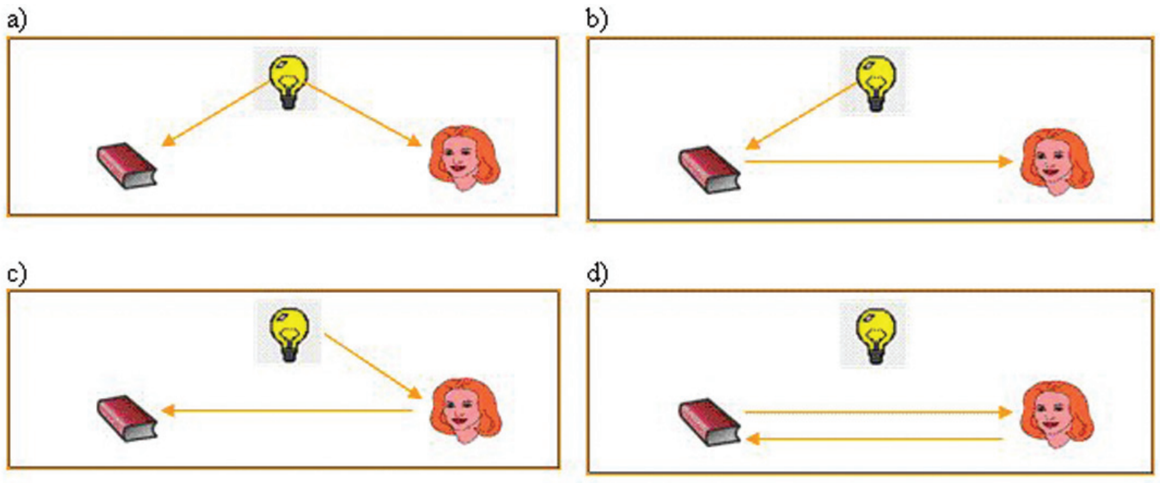
12. Which of the pictures below better represents the mechanism for which we see objects around us?



Explain briefly

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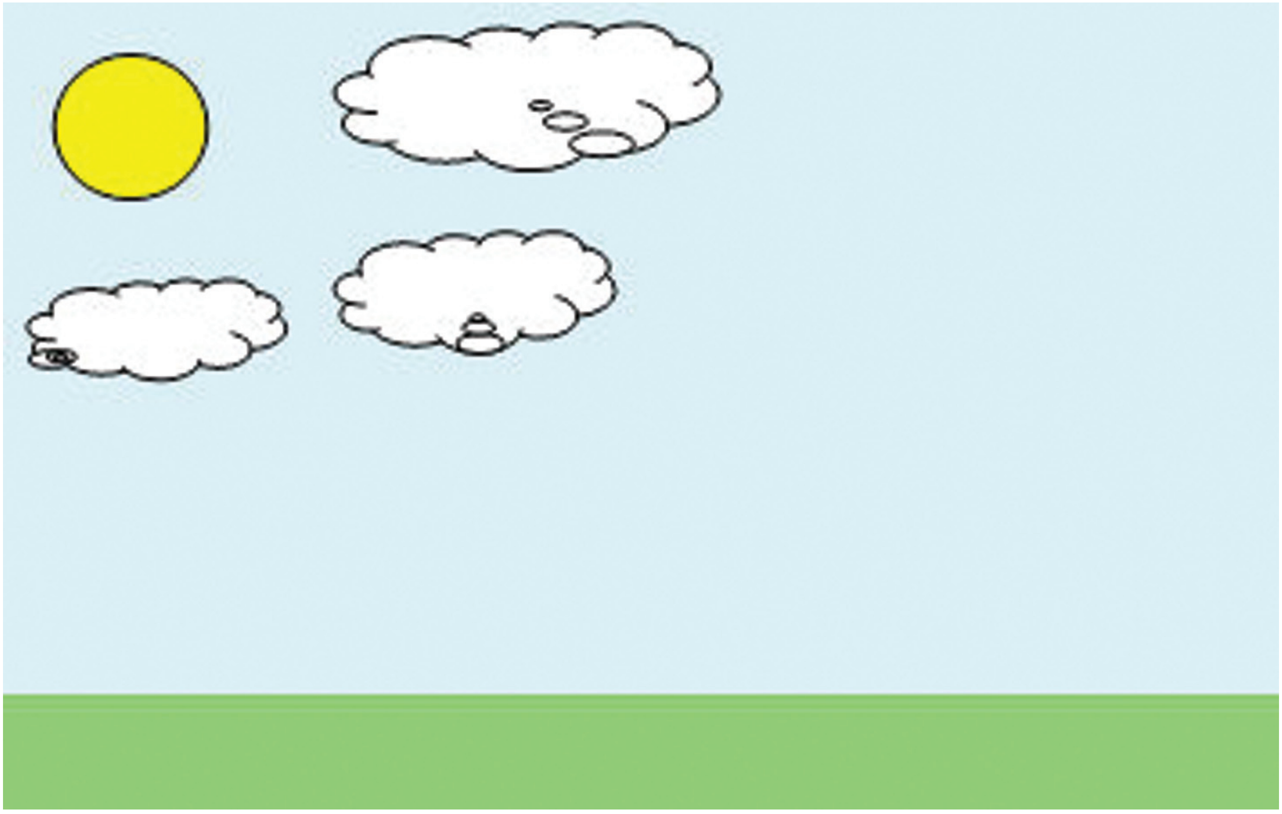
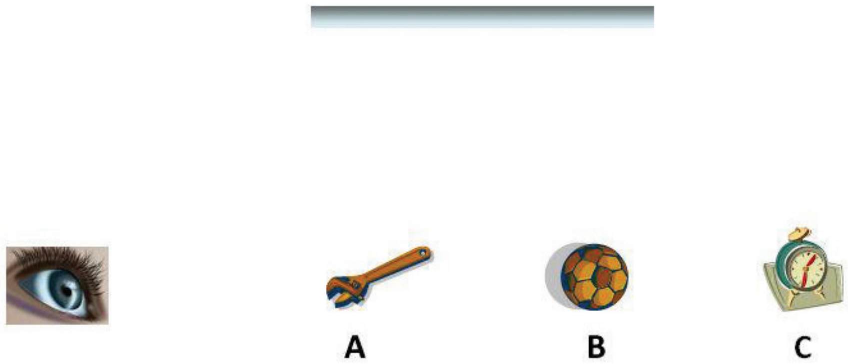
13. Look at the pictures below.
   (a) Draw how the light travels at the figure



   (b) Why sometimes you can see light beams filtering from the clouds?

14. **Which of the following objects the observer is able to see at the mirror?**



Justify your answer.

15. **What happens when light hits a still water surface? Choose the correct answer.**

(a) All the light comes back in the air. ☐

(b) Light will travel only in the water. ☐

(c) Some light will travel in water and some will come back in air. ☐

(d) All the light is captured by water. ☐

(e) We need more information about the nature of the water surface. ☐

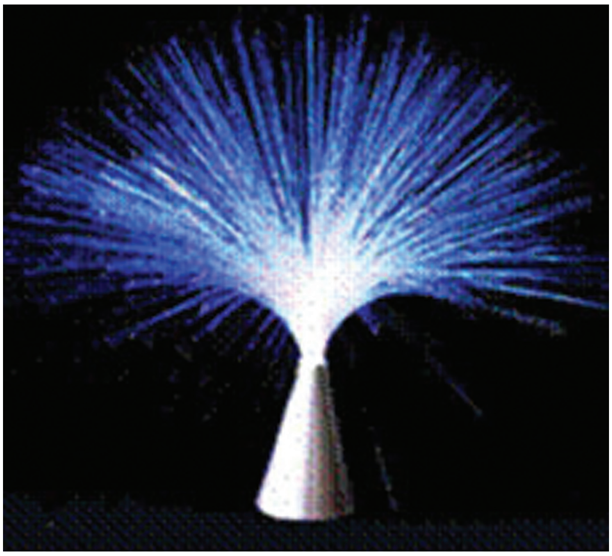
16. **What materials are made of the optical fibers of the lamps (see picture)?**

(a) Plastic. ☐

(b) Glass. ☐

(c) Rubber. ☐

(d) Ceramic. ☐



17. **Is it possible to guide the light within:**

	YES	NO
(a) a whole plastic tube surrounded by air?		
(b) a whole plastic tube surrounded by water?		
(c) a hollow plastic tube?		
(d) a hollow glass tube?		
(e) a whole glass tube surrounded by air?		
(f) a whole glass tube surrounded by water?		

18. The picture represents a laser beam travelling from the water contained in the tank to the air above the water surface. The beam intensity is greater in air than in water because:

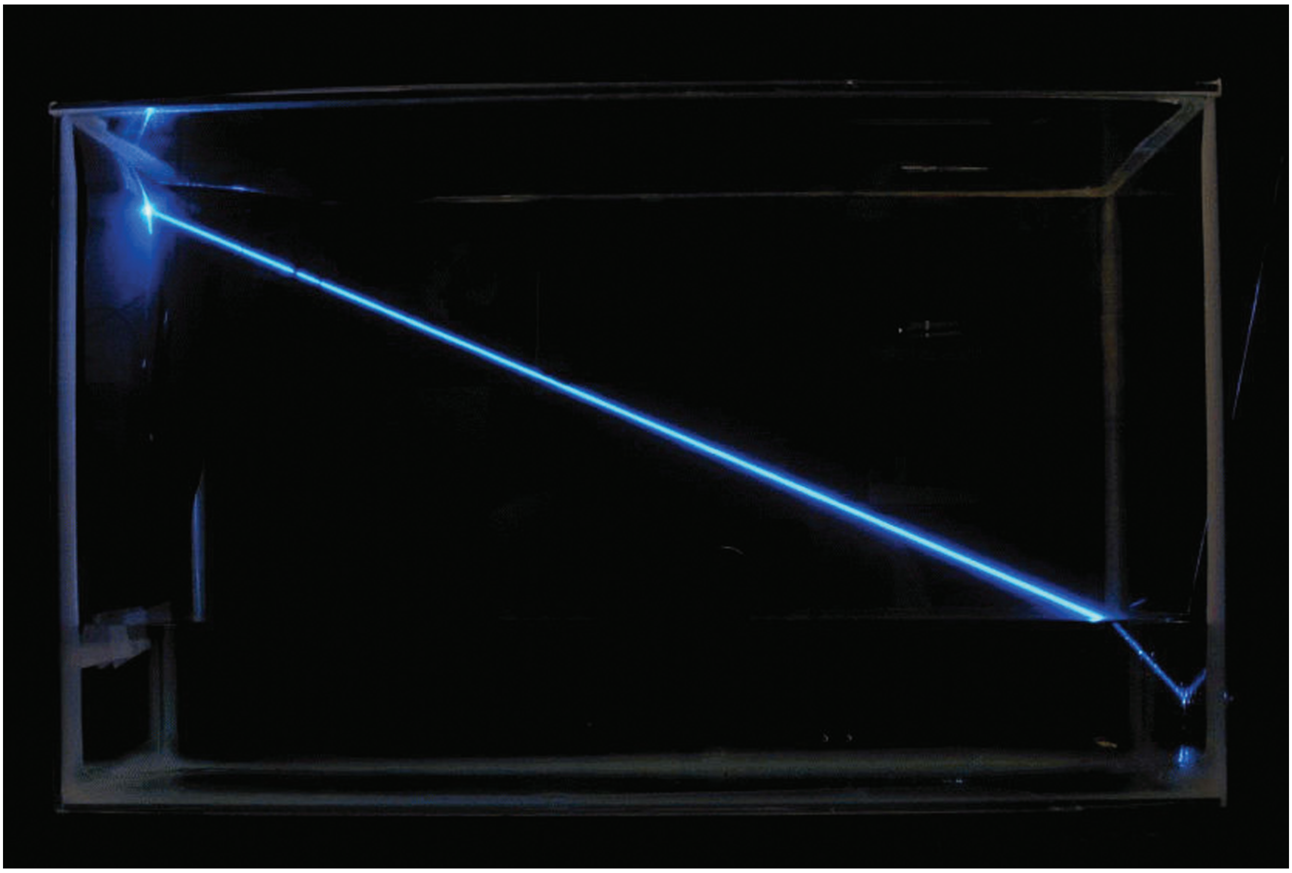
(a) air captures more light than water. ☐

(b) there is less water in the tank than air. ☐

(c) air is less dense than water. ☐

(d) air particles are smaller than the water particles. ☐

(e) some particles that diffuse light more than the particles in the water tank have been added in the air. ☐



Explain briefly.

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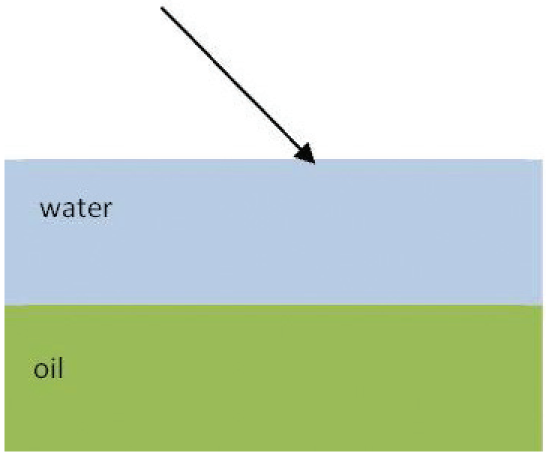
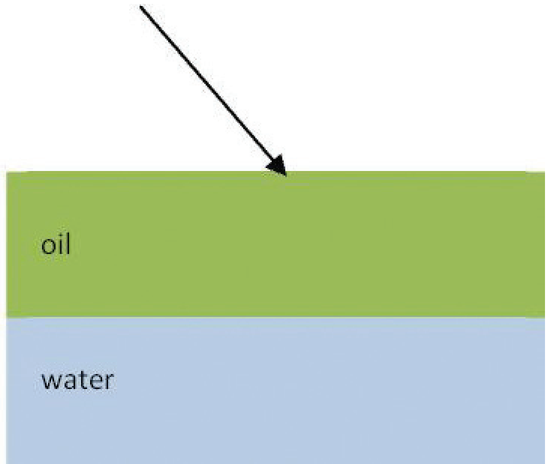
19. **Draw the laser beams as they travel through the media (n_{water} =1.33 ; n_{oil} = 1.67)**

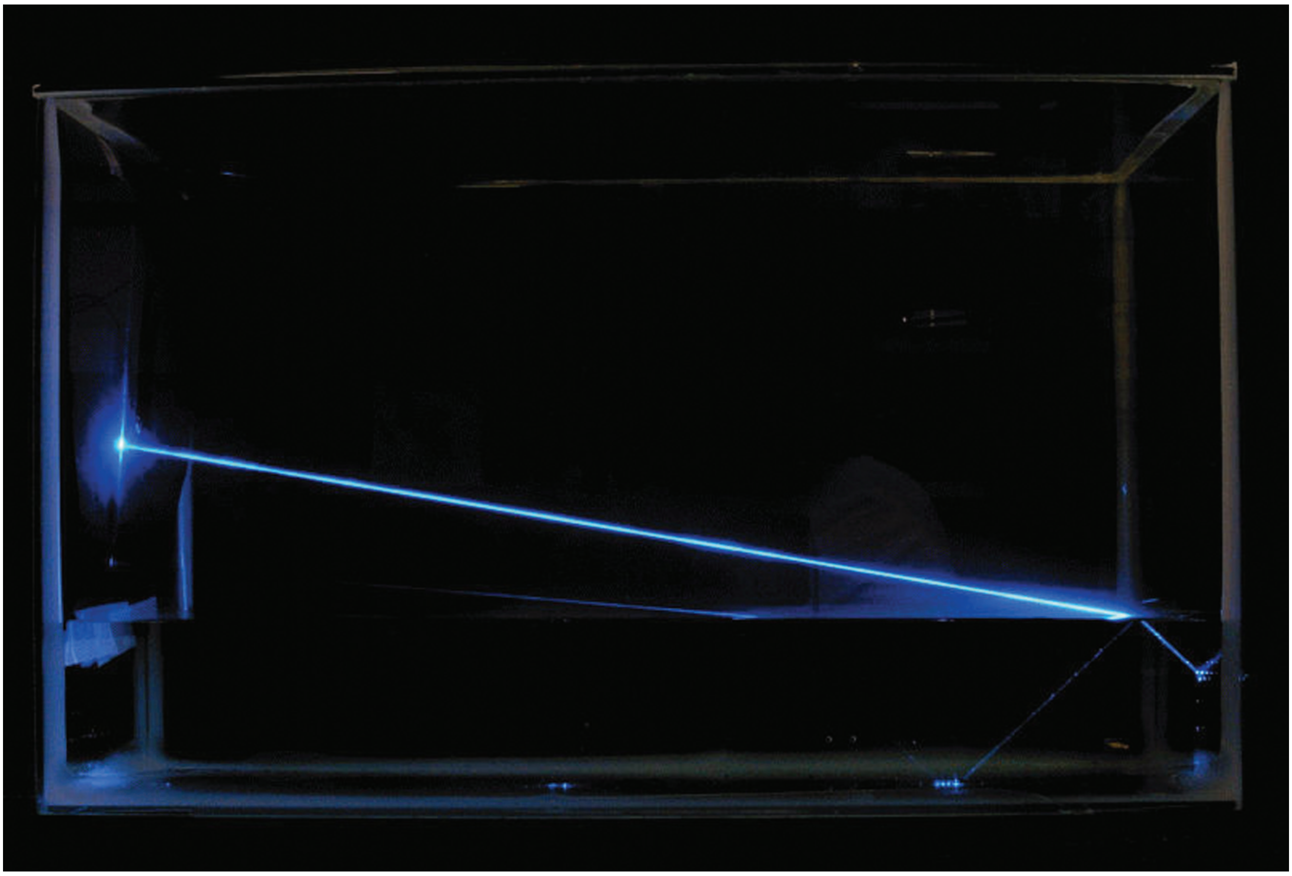




20. **According to your idea, is it true that:**

	YES	NO
(a) index of refraction is a property of materials.		
(b) to measure the refraction index of the water is necessary to measure the intensity of a light beam propagating in the water.		
(c) the value of the refraction index of a substance depends on the quantity of substance.		
(d) to measure the refraction index of a substance with respect to another, it is sufficient to know the critical angle between them.		
(e) to measure the refraction index of a substance it is necessary to know its density.		

21. **The picture represents a laser beam travelling from the water container in the tank to the air above the water surface. Observe points the P and Q where the laser beam hits the water surface.**



	YES	NO
(a) In P there is reflection		
(b) In P there is refraction		
(c) In Q there is reflection		
(d) In Q there is refraction		

22. Which of the following sentences is true?

Note that here the "refraction index" is relative to that of the air which for our purpose can be taken as 1.

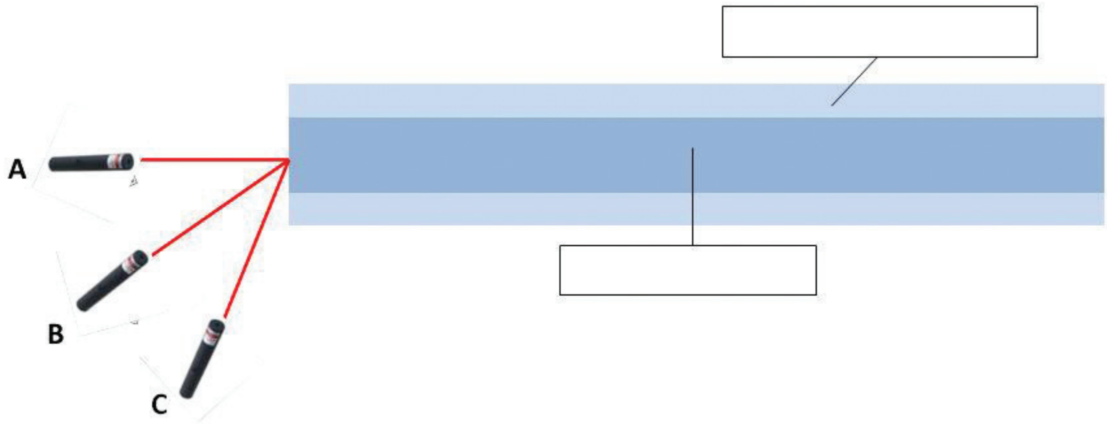
	TRUE	FALSE
(a) A substance's refraction index depends on the quantity of substance.		
(b) If two materials have different densities, then the material that is more dense has a greater refraction index.		
(c) A materials' refraction index depends on the volume of the material.		
(d) A laser beam is brighter in the materials with greater refraction index.		
(e) A laser beam entering at the same angle into two materials with different refraction indices, is refracted more in the material with a greater refraction index.		

Explain your answer.

23. According to your idea, is it true that:

	YES	NO
(a) light traveling from water to air can undergo total reflection.		
(b) the critical angle between two materials depends only on the refraction index of the material in which the light is totally reflected.		
(c) light travelling from air to water can undergo total reflection.		
(d) total reflection is a phenomenon which occurs when light travels from a less refractive to a more refractive material.		
(e) given a light beam travelling from material 1 to material 2, the critical angle of material 1 with respect to material 2 is the smallest incidence angle for which there is no refraction in material 2.		

24. In which of the following cases the light beam will arrive at the other side of the optical fiber?
(Name the optical fibers' parts and use the ray model).



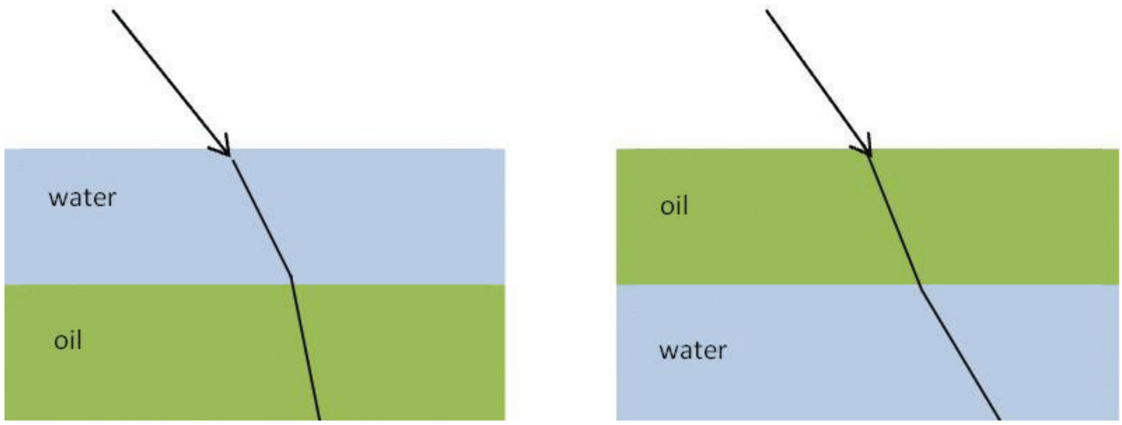
Justify your answer.

RUBRICS

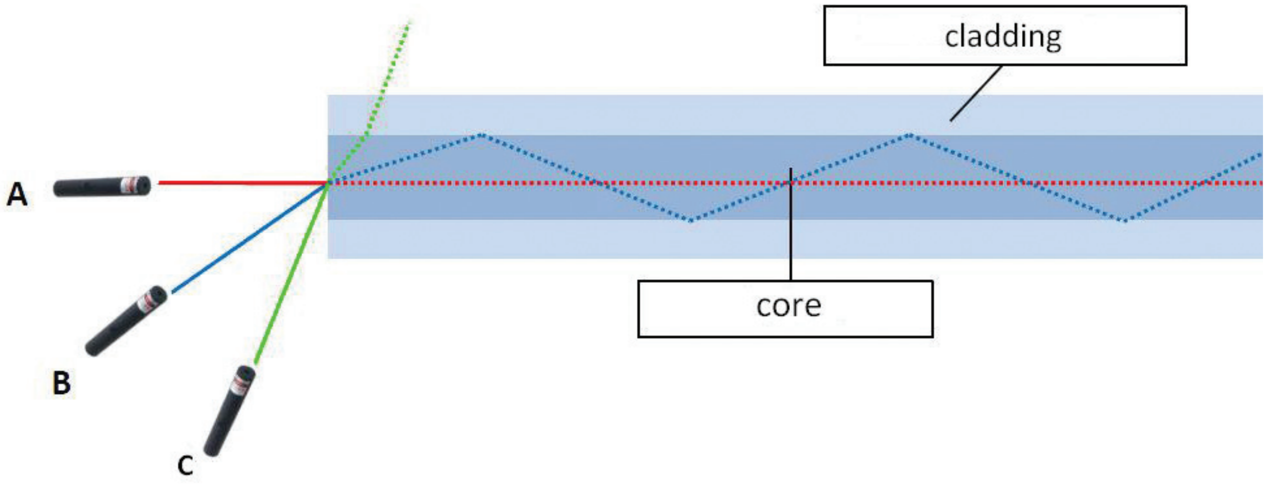
POST – TEST

1. Objects diffuse the light (that enters our eyes) that reaches them from a light source. If there is no such source no light can enter our eyes. (1 point)
2. Light source lightens up the object which reflects part of the light into our eyes. (1 point)
3. a) Rectilinear propagate of light near clouds. (0,5 point)

   b) Light is scattered and diffused by vapor molecules near the clouds. (1,5 point)
4. He will see only B and C objects for which inclination angle is equal with reflection angle as light propagates from object to observer. (1,5 point)
5. c) (point 1)
6. Optical fibers are made by glass in order to transfer light at long distances without remarkable attenuation aiming to transmit signals or messages. (point 1)
7. Yes – Yes – No – No – Yes – Yes (point 2)
8. e) (point 0,5)
9. See below figure (point 2)



10. Yes – No – No – Yes – No (point 2)
11. All Yes. In P and Q light beams do not hit at the critical angle. (point 1)
12. All FALSE. Refraction index is a property of material. The last answer is a consequence of Snell law. (point 1)
13. Yes – No – No – No – Yes (point 2)
14. Write core – cladding (see above figure). It will arrive only A and B laser beams. Laser beam C enters at the core of optical fiber with larger acceptance angle and will be refracted. (point 2)


cladding
A
B
C
core

PROTOCOL OF SEMI-STRUCTURED INDIVIDUAL INTERVIEW

ABOUT SCIENTIFIC MODELS

One aim of the Greek version of the Teaching Learning Sequence on the Optical properties of Materials as implemented was the improvement of students' awareness about the nature, the purpose and use of scientific models through appropriate designed activities. More specifically, it was intended that students will the nature and purpose of models and their strength and weakness to discriminate models from reality and understood that models represent an idea and are considered as simplifications or abstractions of reality in order to describe and visualize, interpret and predict phenomena.

In order to elicit students' ideas about the nature and propose of scientific models before and after the implementation of the Teaching Learning Sequence, a semi-structured interview protocol was designed and addressed to the pupils. During this process, through appropriate prompts student reveal their ideas for the following issues:

- What do you believe that a scientific model is? What could it represent? Give an example.
- How accurately should a scientific model represent the reality? Justify your answer.
- Is it possible for a scientific model to change? Yes or no? Why?
- Could there be different models for the same phenomena? Yes or no? Why?
- Which could be the purpose of a scientific model? How it might be useful?

MATERIALS SCIENCE PROJECT

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