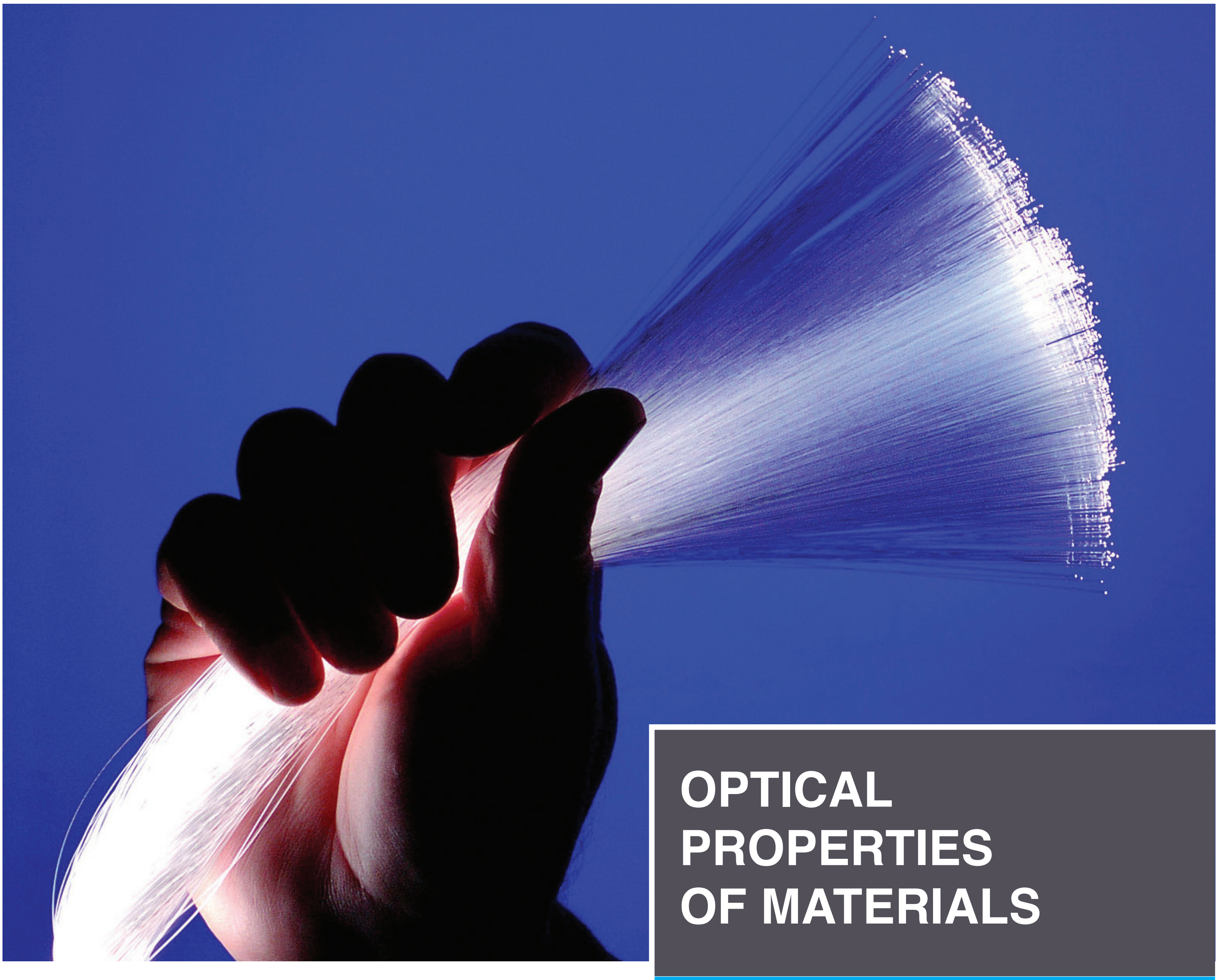

OPTICAL PROPERTIES OF MATERIALS

TEACHING AND LEARNING ACTIVITIES

ORIGINAL 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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CONTENTS

UNIT 0: VISION

0.1 HOW DO WE SEE?

In this activity we will investigate about the mechanism of vision and the role of materials in this process

0.1.1. EXPERIMENT: Light in the box

Look at the pen on your table. Place the pen in the box and look through the hole in the upper side of the box.

Do you still see the pen? Describe.

Send the light in the box through the hole there is in one side.

Do you still see the pen? Send the light with the torch in another direction. Do you still see the pen?

0.1.2. EXPERIMENT: Laser sword

Point the laser towards the wall.

Describe what you observe.

You can make the air "dirty" with chalk powder or smoke.

Describe what you observe.

What can you conclude?

0.1.3. ACTIVITY: Diving in clear waters

In the above activities both you and the objects you observed are in air. Imagine to be diving, with the pen, in a swimming pool full of water.

Describe how you think you see the pen.

Imagine that the swimming pool is filled with mud and you and the pen are within it.

Do you still see the pen? Explain

What can you conclude?

UNIT 1:
LIGHT GUIDES

1.1 OPTICAL FIBERS

In this activity we will investigate what are optical fibers, their basic function and why they are used in telecommunications

1.1.1. EXPERIMENT: Fiber optics lamp

Make a bundle of optical fibers and tight them together at one extreme. Light a lamp near one extreme of the bundle.

What are the most evident similarities and differences between this lamp and a "normal" lamp?

1.1.2. EXPERIMENT: Bending a fiber

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; connect one end of the fiber to the 4.5 V battery.

Describe what you observe on the screen.

Leave the screen and the bulb fixed and bend the fiber.

Describe what you observe on the screen.

1.1.3. EXPERIMENT: Sending signals

This experiment has to be performed by a couple of students: your peer holds one end of the fiber and the laser and you stay behind the door and observe the other end of the fiber.

TELL YOUR FRIEND WHAT SIGNALS (SHORT, LONG, HOW MANY) YOUR PEER SENT YOU AT THE OTHER END OF THE FIBER.

Repeat the experiment with the plastic tubes you have.

Describe.

1.1.4. ACTIVITY: What optical fibers are for?

Collect all information and try to understand what an optical fiber can be used for.

How would you describe an optical fiber? What are its main characteristics?

1.2 IS IT POSSIBLE TO MAKE A LIGHT GUIDE?

In this activity we will see that it is possible to construct, in the school lab, a light guide, and observe what happens when light travels along it.

1.2.1. EXPERIMENT: The water jet

FIGURE W-1

Laser light is directed through the plastic tank filled with water and parallel to the tank base. The plastic tank has a hole from which water exits.

I. Observe what happens if you hit the hole with the laser beam.

Write down your observations

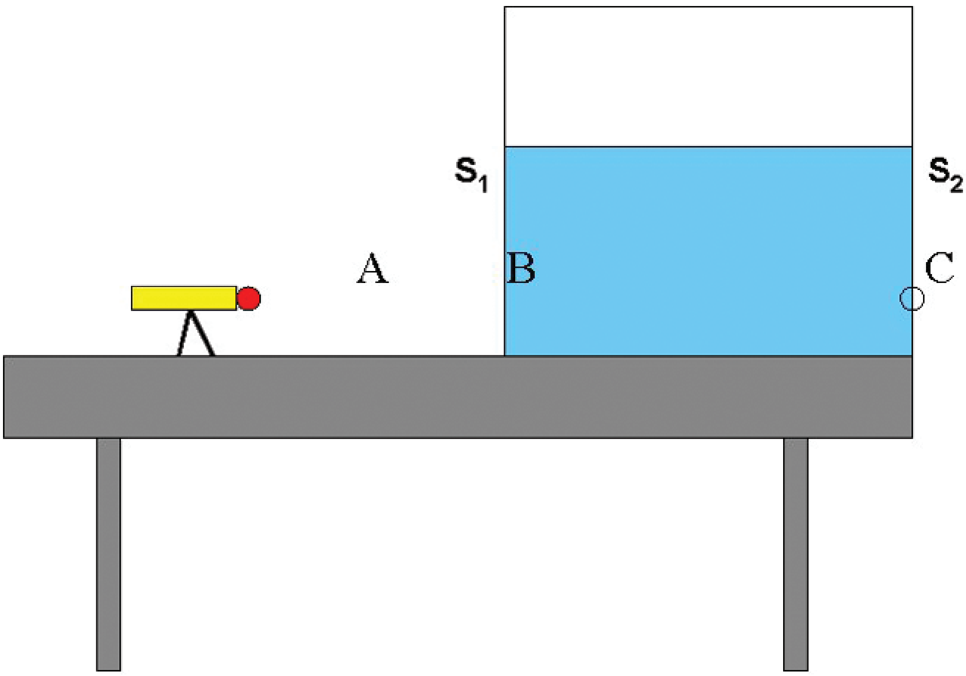
....

....

....

The figure shows the experimental set-up. Sketch the light path from the laser source to the basin that collects the water.

FIGURE W-2



II. Now, focus your attention on the path of light in AB and BC.

Describe what you observe.

How is the light path when it travels in air (AB in the above figure)? [1]

How is the path of light when it travels in water (BC in the above figure)?

What conclusions can you draw?

III. Focus, now, on the light path in the water jet

Give a detailed description of what you see in the water jet.

What conclusions can you draw?

1. *To be able to see the laser beam in the air, "dirty" the air by adding some particles. In this way you can see the path of light.*

1.3 OBSERVING THE LIGHT PATH

In this activity we will observe situations where light deviates from its rectilinear path and build up a suitable setting to perform some measurements.

1.3.1. EXPERIMENT: The water tank

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.

Observe in how many ways you can hit point C (which simulates the position of the hole of the previous experiment) with the laser pointer. Send the light beam in a direction that is **not** parallel to the tank's base.

Describe in detail under what conditions you succeeded in hitting the hole.

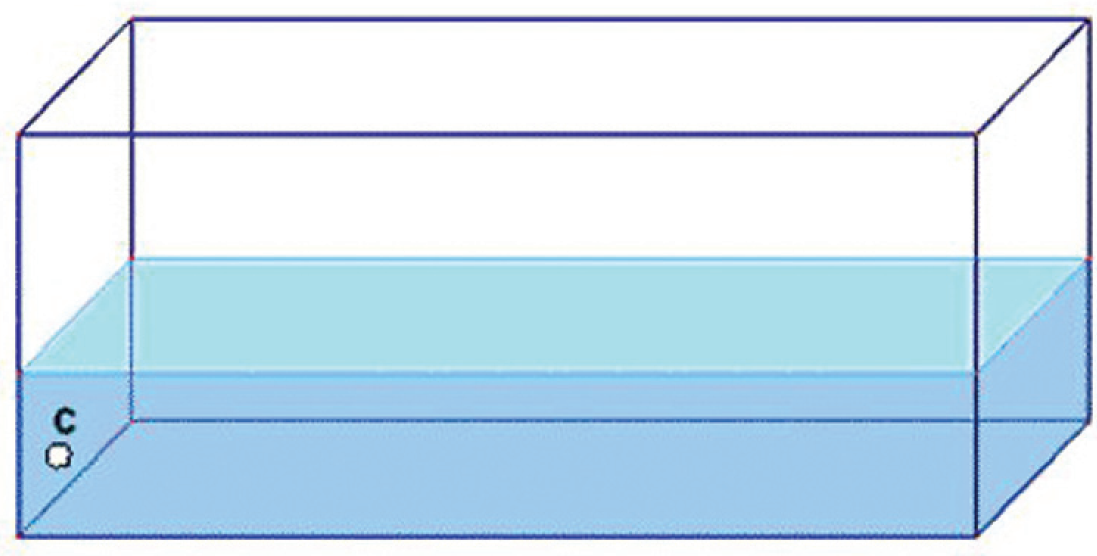
....

....

....

Sketch in the figure below at least two different light paths, with different colours, in air and in water, corresponding to a fixed orientation of the laser pointer. Draw on the figure also the position of the laser pointer for each choice.

FIGURE W-3



Explain your drawings

Do you notice differences in the visibility of the light path in air and in water? Describe in the different cases.

1.4 WHEN AND HOW DOES LIGHT DEVIATE? REFRACTION

In this activity we will study light behavior as it is refracted from a surface. We will hence define the refraction index and formulate the refraction law.

1.4.1. COMPUTER ACTIVITY: Measurement of the refraction index

Open the file "**refraction_image.fig**" with the software Cabrì

Use the software options to:

- *superimpose a ray r on the water surface*
- *superimpose a ray a to the light beam that travels in air; call A the intersection point between a and r. Superimpose a segment AB to a, in order to identify completely the light beam travelling in air.*
- *superimpose a ray b to the light beam travelling in water; call C the intersection point between b and r; superimpose a segment CD to ray b in order to individuate completely the light path travelling in the water.*
- *trace the perpendiculars n and m to the water surface through points A and C where rays a and b meet the water surface; make A and C coincident and thus also n and m*
- *trace two parallel rays p and q to the water surface and through points B e D respectively*
- *identify the intersection points between p and q and the perpendicular m = n to the water surface. Call these intersection points E and F respectively.*
- *trace the segments BE and DF;*
- *identify the triangles ABE and CDF and measure their sides AB, BE and CD, DF (A and C coincide);*

AB = __________; BE = ____________; CD = ______________; DF =________________

Determine the ratios $\frac{BE}{AB}$ e $\frac{DF}{CD}$

$\frac{BE}{AB}$ = ____________________; $\frac{DF}{CD}$ = ____________________

Determine the ratio $\frac{\frac{BE}{AB}}{\frac{DF}{CD}}$ = ____________________

We shall call this ratio "**refraction index of water relative to air**".

Save your file with the name "**refractionindex_group…**"

1.4.2. COMPUTER ACTIVITY: Refraction index as a materials' property

Open the file "**refraction_index.fig**"

Fix the value 1 for the number called "refraction index of material 1" (n_1= 1) and 1,33 for refraction index of material 2 (n_2= 1,33). Fix a value for the angle α and write the data in the Table below.

QUANTITY	VALUES
sin β	
sin α	
$\frac{\sin(\alpha)}{\sin(\beta)} = \frac{n_2}{n_1}$	

Modify the value of the inclination angle of the laser (α) and write down the values in the Table below.

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

Fix the value of the inclination angle α, modify the water height (h), selecting point H and write down the values in the Table below

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

1.4.3. ACTIVITY: Snell's law of refraction

Modify the material in the tank, by modifying the refraction index of material 2 according to the values of column one of Table below and write down the value of the refraction angle β

MATERIAL 2	(β)
Olive oil (n=1,46)	
Gasoline (n =1,49)	
Sunflower oil (n=1,65)	

Look what happens to the angle β as you increase material 2 refraction index. What conclusions can you draw?

1.5 WHEN AND HOW DOES LIGHT DEVIATE? REFLECTION

In this activity we will investigate about the law of reflection. We will also determine the water-air critical angle.

1.5.1. COMPUTER ACTIVITY: Refraction and reflection

Open the file “**reflection_refraction.fig**”.

I. Identify (and mark with different colours) the light beams that travel in air and water; measure the angles they make with the normal to the water surface at the intersection points.

Are the angles that the light beams form in water with the normal the same? Are they different? Explain.

Compare the angles that the light beams form in air with the normal and the angles that the light beams form in water (with the normal).

Are they the same? Different? Explain.

II. Look at the photo and compare this situation with that of Experiment 1.3.1.

Light has been sent from water to air or vice versa?

1.5.2. COMPUTER ACTIVITY: Measuring incident and reflected angles

Open the file “**multiple_reflection.fig**” with Cabrì.

Trace all the rays for the light beams you see in the picture. Trace and measure the angles that the reflected light beams form with the normal.

Focus on each pair of adjacent angles. Are such angles the same? Different? Comment briefly

1.5.3. COMPUTER ACTIVITY: Measuring the critical angle

Open the file "**critical_angle.fig**" with Cabrì.

Let the refraction index of medium 1 be $n_1 = 1$ and $n_2 = 1,33$ that of medium 2 (relative to air).

Place on the normal n' the semi-ray α that represents the incident beam. Turn α until you cannot see any more the refracted rays in air.

Use the software options to measure the incidence angles θ_i and reflection θ_r of the light beam at the interface water-air.

Focus your attention on each pair of adjacent angles θ_i e θ_r .

Write down their values here below.

....

....

....

Call $\theta_i = \theta_L$ the smallest angle for which you don't see any more the refracted beams.

θ_L = ...

θ_L is called "limit angle", or "critical angle"

1.6 HOW IS A LIGHT GUIDE MADE? FIRST CLUES

In this activity we will show that to construct a light guide one must have a transparent medium surrounded by another transparent medium of lower refraction index

1.6.1. ACTIVITY: Introducing core and cladding of a light guide

I. Look carefully at the picture of experiment 1.3.1 (the water tank): light beam deviates both in the "upper" part (interface π) and in the "lower" part (interface σ) of the tank.

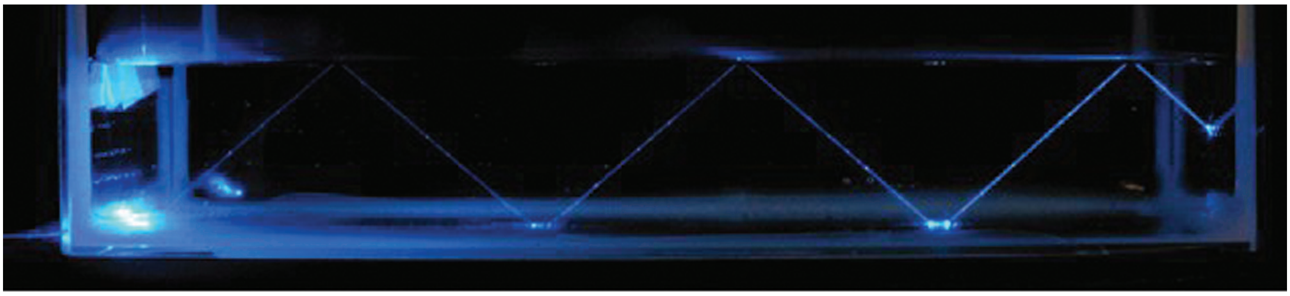


FIGURE W-4

What are the materials that form the interfaces at the upper and lower parts of the tank?

....

....

....

Do you see any differences in the behaviour of light on the two interfaces?

....

....

....

II. Look carefully at the picture of experiment 1.2.1 (the water jet). In the jet, light undergoes total reflection

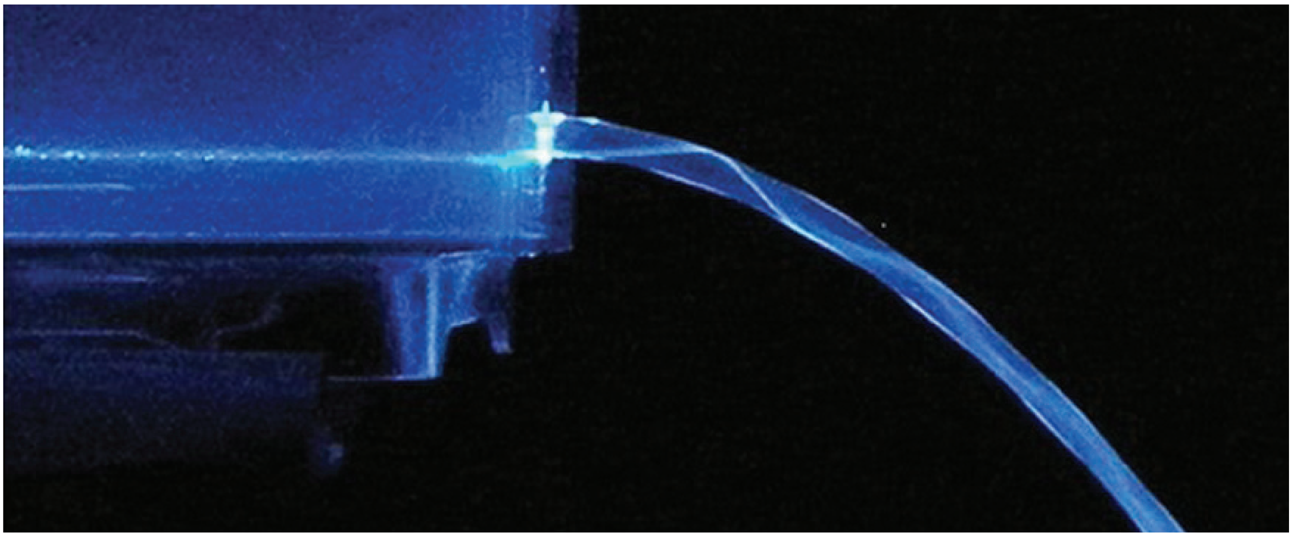


FIGURE W-5

Identify the couple of materials where total internal reflection occurs?

III. Which common objects can be used to build a light guide? Identify for each of them the material of the core and that of the cladding

UNIT 2:
FROM LIGHT GUIDES TO OPTICAL FIBERS

2.1 DO WE WANT TO SEE THE LIGHT PATH IN THE FIBER?

In this activity we will deal with the attenuation of light as it travels in a medium. We will also show that transparency has to do with light attenuation ands that the attenuation in optical fibers mainly occurs at the interface between core-cladding.

2.1.1. ACTIVITY: Transparent materials

For which applications could the water-jet experiment be useful? Signal transmission? Which are the main problems?

Is it really important to see the light path in a light guide?

Write some examples of transparent materials

2.1.2. EXPERIMENT: Influence of matter on transparency

Point the laser towards the wall. Place a paper tissue between the laser light and the cardboard.

Describe what you observe as you take off more tissue layers.

2.1.3. EXPERIMENT: Scratching the surface

Your teacher performs the following experiment:
scratches part of the fiber and sends laser light in the fiber.

Describe what you observe and make hypotheses for the observed behaviour.

2.1.4. ACTIVITY: Identifying a good cladding

In all the experiments you performed air has been the cladding for the light guide.

Do you think air is a good candidate for constructing an optical fiber?

....

....

Enrich the description of the properties of the materials of an optical fiber .

....

....

....

2.2 OPTICAL FIBERS' CHARACTERISTICS

In this activity we will become aware that there is a maximum angle at which the light sent in the fiber propagates in the fiber's core; we will also investigate on the influence of core and cladding's refraction index on this angle. Finally we will study optical fiber's main characteristics and relate them to the materials' optical properties.

2.2.1. EXPERIMENT: Introducing the acceptance angle

Send the laser beam at the end of the glass bar and observe if the opposite end is lighted or not. Turn the laser and observe what happens as you change the entrance angle of light into the glass bar.

Do you always see the opposite end of the bar lighted?

2.2.2. EXPERIMENT: Role of the cladding in determining the acceptance angle

Dip half of the glass bar in a glass of water. Send the laser light at one end of the glass bar and remark if you see any difference when the glass bar is in air or in water.

The maximum angle for which you still see light at the opposite end of the bar is smaller or greater when the bar is in water or in air?

2.2.3. COMPUTER ACTIVITY: Calculating the acceptance angle

Open the file "**optical_fiber.fig**"

I. **Write down the value of the maximum angle θ_a for which you have total internal reflection in the core.**

θ_{amax} = acceptance angle = ...

Write down $2\theta_{amax}$ = angular aperture = ...

What can you say about the light beams that enter the fiber at angles less or equal than $2\theta_{amax}$?

II. **Let's investigate how and if θ_{amax} depends on the core's and cladding's refraction indices. Fix a value for the core's refraction index n_n = 1,50.**

Fix initially the cladding's refraction index to the value n_m = 1,10 and fill the table.

θ_{amax} (°)	n_n	n_m	n_n-n_m
90	1, 50	1,10	
	1,50	1,20	
	1,50	1,30	
	1,50	1,40	
	1,50	1,47	

How does θ_{amax} vary if the difference n_n-n_m increases?

UNIT 3: OPTICAL FIBERS AS TRANSMISSION CABLES

3.1 HOW CAN WE RECOVER INFORMATION?

In this activity we will deal with problems in telecommunications when more signals (light beams) travel along a fiber. We will address time delay and information receiving. Finally we will find out the relationship between modal dispersion and refraction indices of core and cladding.

3.1.1. ACTIVITY: Signals' pathway

When two signals can enter a fiber and propagate along it by internal reflections you may have a situation as that of the schema below, where parts of two rays **α** and **β** are represented respectively by the two segments L_2 and L_1.

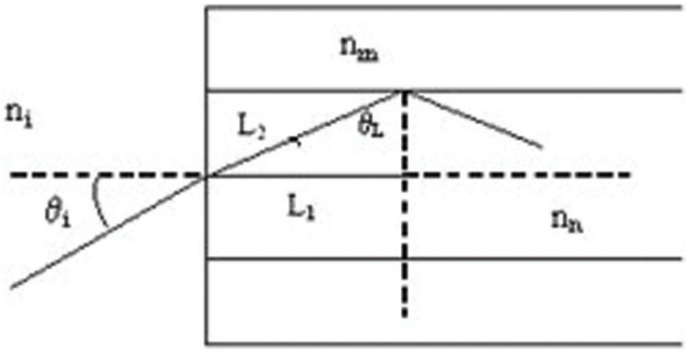


FIGURA W-6

Which of the two rays has the shortest path along the fiber?

Which of the two rays has the longest path along the fiber?

3.1.2. ACTIVITY: Which signal travel faster?

Light travels in vacuum with constant velocity. Its speed is c=300000Km/s.
When light encounters a medium different from the vacuum, its speed decreases.
The speed of light in a medium depends on the medium refraction index v=c/n.
In the fibers' core n = 1,5 (glass) and the speed of light is v=c/1,5.

What ray travels along the fiber in the shortest time?

What ray travels along the fiber in the longest time?

3.1.3. COMPUTER ACTIVITY: Introducing modal dispersion

Open the file “**modal dispersion.ppt**”

Observe the simulation and explain in all cases what happened and why.

3.1.4. COMPUTER ACTIVITY: Evaluating modal dispersion

Open the file “**times.fig**”

Select a value for the core’s refraction index n_n = 1,50 and cladding’s refraction index n_m = 1,47
Observe the rays a and b, that are superimposed respectively at θ_a=0° and θ_a=17,3°.
Δt is the difference between the times needed by the two rays a and b to reach points Q and P

Write down the value of Δt

Δt =……………….

How can you reduce the value of Δt? Explain

Infer a qualitative relationship between the value of Δt and the physical parameters of the system

Derive a quantitative relationship between the value of Δt and the physical parameters of the system

3.2 A GRADED INDEX OPTICAL FIBER

In this final activity we will design a graded index optical fiber.

3.2.1. COMPUTER ACTIVITY: Addressing modal dispersion

Open the file “**graded_index.ppt**”

Observe the simulation and explain what you think is different from the previous simulations

3.2.2. EXPERIMENT: Light trajectory in variable refractive index materi-

Observe the teacher performing the experiment.
He has pointed the laser beam parallel to the tank basis, approximately at half height.

Describe the laser beam trajectory.

What optical property of the material can be responsible for such a trajectory?

Do you think you could superimpose a segment or a ray to the path of the laser beam in water?
A curve?
Briefly justify your answer.

3.2.3. COMPUTER ACTIVITY: Step and graded index optical fibers

Open a browser and go to the URL
http://www.sciences.univ-nantes.fr/physique/perso/gtulloue/optiqueGeo/dioptres/fiber_optique.html

Select "Saut d'indice" (Step Index) and 1,5 for the core refraction index (you can do this by moving the red balls in the diagram on the left), and 1,47 for the cladding refraction index. If you send an impulse in the fiber (select "impulsion") you may observe how the beams propagate in the core.

Describe in words

Repeat the same steps by selecting now "gradient constant" (the refraction index in the core varies at a constant rate) and send the impulse in the fiber ("impulsion")

Describe in words

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