PHABLABS 4.0

PHOTONICS WORKSHOP

A CURIOUS SUSPECT

Determination of sugar content by means of a home-made refractometer

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PROPERTIES OF THIS WORKSHOP

SUMMARY:

The Refractometer activity is based on a story telling (lecture of the diary) that allows discovering the properties of the light, and in particular the concepts of the absorption, reflection, total internal reflection and refraction.
All the steps reported in section 5 are organized in a chronological sequence, in order to explain the activities that will be carried out during the workshops. In red are highlighted the parts of the diary. The students will work in groups (4 or 5 students for group). Each group will have the name of a prestigious and famous laboratory in the field of Photonics. (for them the acronyms won't have any significance, but we will introduce them)
Following the hints and suggestions written in the diary, they will discover, in addition to the lavishness of uncle Ben, how to perform the experiments and to realize their own instrument.

TARGET AUDIENCE:

Young students (10-14 years old)

SUGGESTED TIME PLANNING: (Total: 1h30)

Timing in minutes	**activity**
0 - 15	Familiarizing with the concepts of absorption, reflection, total internal reflection.
15 - 30	Understanding the concept of refraction
30 - 55	Implementation of the refractometer
55 - 90	Determination of the sugar content in a drink by the refractometry.

TOOLS:

Laser Cutter

WEBLINK:

All needed files for lasercutting andWemos can be found on:
http://www.phablabs.eu/workshop/refractometer
or via the QR code.

Step 1:Technology of light behind

What is the light? How does light behave?
Some concepts must be clarified for the purposes and the activities of this workshop:

•we can only see light when it is reflected off an object or our eyes intercept rays from a light source
•light travels in straight line and changes its direction when an object in its path reflects the beam
•we can see the objects because light travelling from a light source to the object is reflected off the object and impinges our eyes
•different types of objects reflect different amounts of light; in addition to reflection, light can be also partially absorbed or transmitted by an object

1.1: Reflection

Light is reflected when it strikes on a surface or interface between two different materials, for example air/metal, air/water, glass/water. The amount of reflected light at the interface depends on the refractive index of the involved media. The refractive index describes how light propagates through a medium.
The reflection law states that the incidence angle equals the angle of reflection. The reflection is specular in case of a smooth, mirror-like surface. In case of irregular surfaces, the light rays are reflected in many directions (diffuse reflection). In this case, the law of reflection is still obeyed for each ray hitting a small portion of the reflective surface.

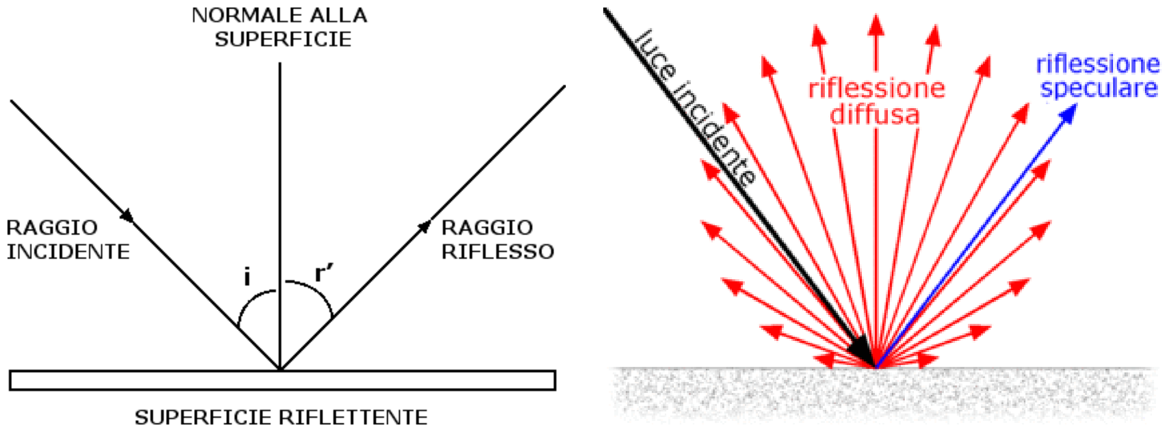


Figure 1.1: Specular and diffuse reflection.

1.2: Refraction

Refraction, in physics, is the change in direction of a wave passing from one medium to another caused by its change in speed.
To explain to young minds students the concept of refraction we can use the following simple cartoon concerning a car traveling between two different surfaces (a) smooth pavement and (b) muddy filed. In the muddy field it slows down as there is more friction. If it enters the field at an angle then the front tyres hit the mud at different times. First to hit the mud is tyre 1, and will move more slowly than tyre 2 (cartoon, left). This causes the car to turn towards the normal. When the car leaves the mud for the road, tyre 1 hits the road before tyre 2 and this causes the car to turn away from the normal (cartoon, right). If the car approached the muddy field at an angle of incidence of 0°, then both front tyres would hit the mud at the same time. The tyres would have the same speed relative to each other so the direction of the car would not change, it would just slow down.

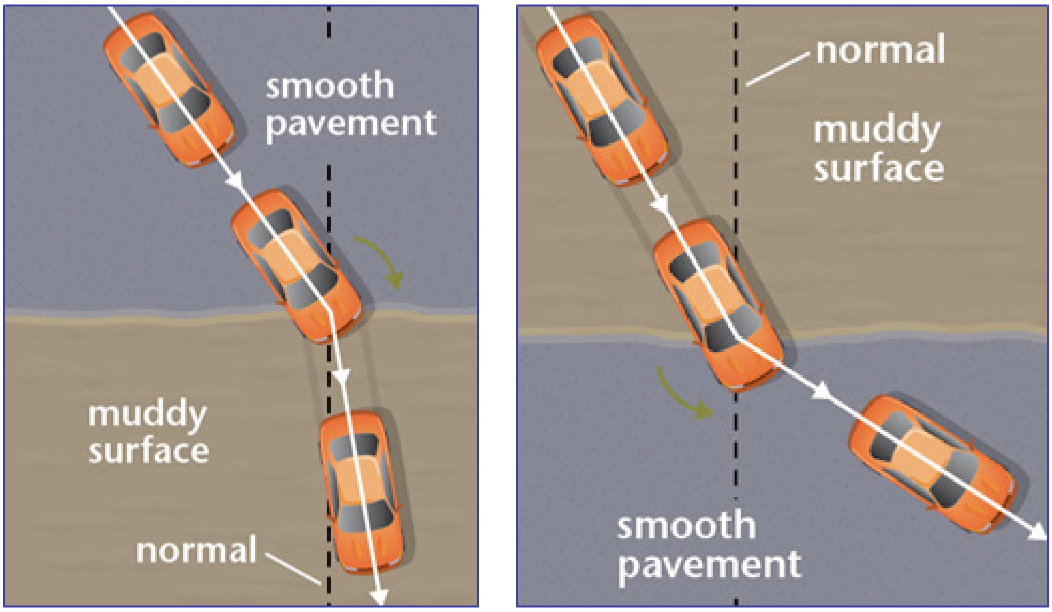


Figure 1.2: Cartoon concerning the refraction phenomenon Copyright 2010 McGraw-Hill Ryerson Ltd.

In the same way a ray of light bends when passes from a "fast" medium to a "slow" medium, characterized by a higher refractive index (as in the cartoon, left) and vice versa (as in the cartoon, right). The refractive index describes how light propagates through the medium and determines how much light is bent, or refracted, when entering a material.
For example, the refractive index of water is meaning that light travels 1.333 times faster in a vacuum than it does in water.

The refraction phenomenon allows explaining "broken pencil" effect shown below. Where submerged objects always appear to be shallower than they are because the light from them changes angle at the surface, bending downward toward the water.

Figure 1.3: "Broken pencil" effect.

1.3: Total internal reflection

The total internal reflection is the phenomenum where light gets reflected inside a particular material over and over again (see figure below).

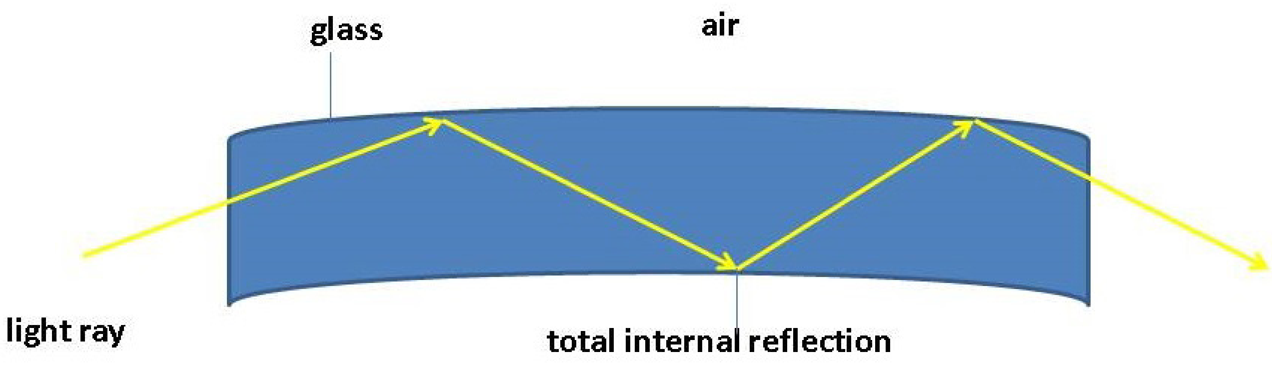


Figure 1.4: Optical fiber: example of total internal reflection.

It occurs when light is directed from a medium (for example glass) with a given refraction index na toward one having a lower refraction index n_b (for example air) and the incidence angle of the beam is larger than the critical angle θ_c. In case the incidence angle is exactly θ_c, the refracted light moves parallel to the boundary interface.
Greater n_a than n_b. smaller is the critical angle to produce total internal reflection. For example, in case of the diamond the refractive index is 2.4 and the critical angle 24.5°. Any light inside the diamond that approaches the surface at an angle greater than this is completely reflected back into the crystal. This property, combined with proper faceting, causes diamonds to sparkle and colorful. The angles of the cutting facets are accurately adjusted so that light is "caught" inside the crystal through multiple internal reflections.

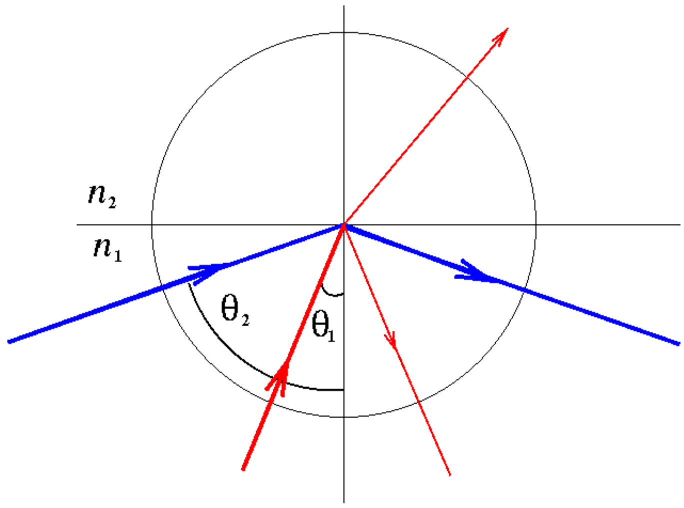


Figure 1.5: Total internal reflection at the interface of two media and in the diamond.

Note: We can explain the concepts by the example of the pool game. The ball mimes the light, the green region is the medium with higher refractive index: the ball experiences multiple reflections. In this case the ball cannot leave the green zone for any angle. The critical angle θc is 0°.

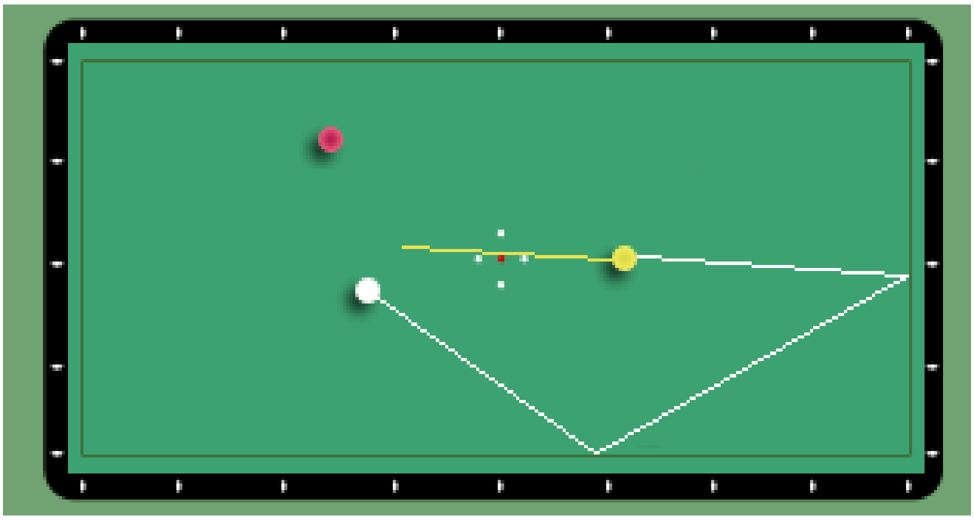


Figure 1.6: Total internal explained by the pool game.

1.5: Transmission and absorption

We know that several phenomena can happen when light impinges the boundary between two different media: part of the light may be reflected back into the material where it came from while part of it is refracted and may continue to travel through the second medium. The portion of the light going through the second material can or cannot be absorbed significantly along the way. The transmitted beam loses intensity. How much intensity we will lose depends on the medium. Window glass, for example absorbs very little light but a brown bottle glass absorbs quite strongly.

1.6: Refractometers

At the same time refraction phenomenon is commonly used in order to develop refractometers that allow measuring the refractive index of different substances. Students can use the physics of refraction to measure the sugar content of a clear liquid solution using a laser pointer and a hollow prism.
What happens if a ray a light wave travels through a prism filled with water? Can you draw how the wave would be refracted?

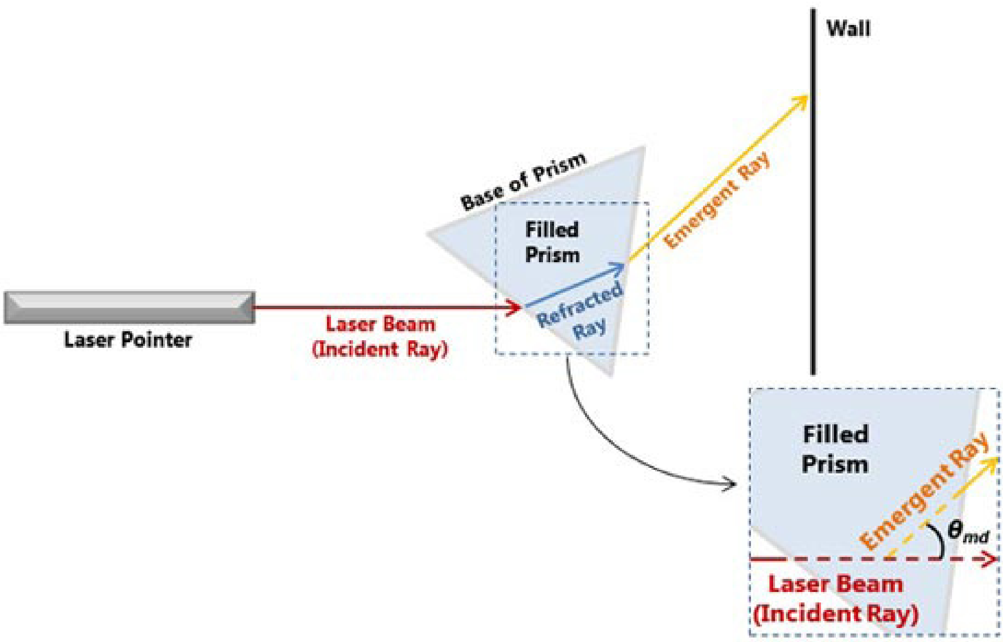


Figure 1.7: Sketch and working principle of the last experiment of the workshop.
As a function of the refractive index of filling solution the angle emergent ray will be different.

Step 2: Parts list

In this section are reported the different type of materials.

The activity proposed by Diary (part 1 e 2) are related:
1) to the familiarization with the concepts of absorption, reflection, total internal reflection
2) to understand the phenomenon of refraction, and the following materials are needed:

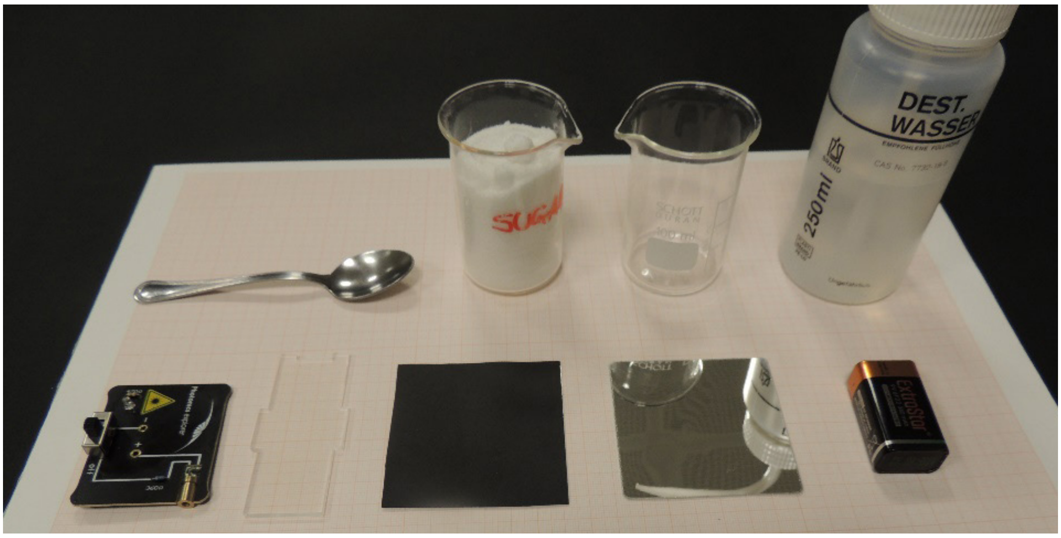


Figure 2.1: List of materials: graph paper, spoon, sugar, becker, distilled water, laser (EYEST), plexiglas, absorptive sheet, mirror, and battery 9V.

The activity proposed by Diary (part 3 e 4) is related to the implementation and the use of the refractometer to determine the sugar concentration.

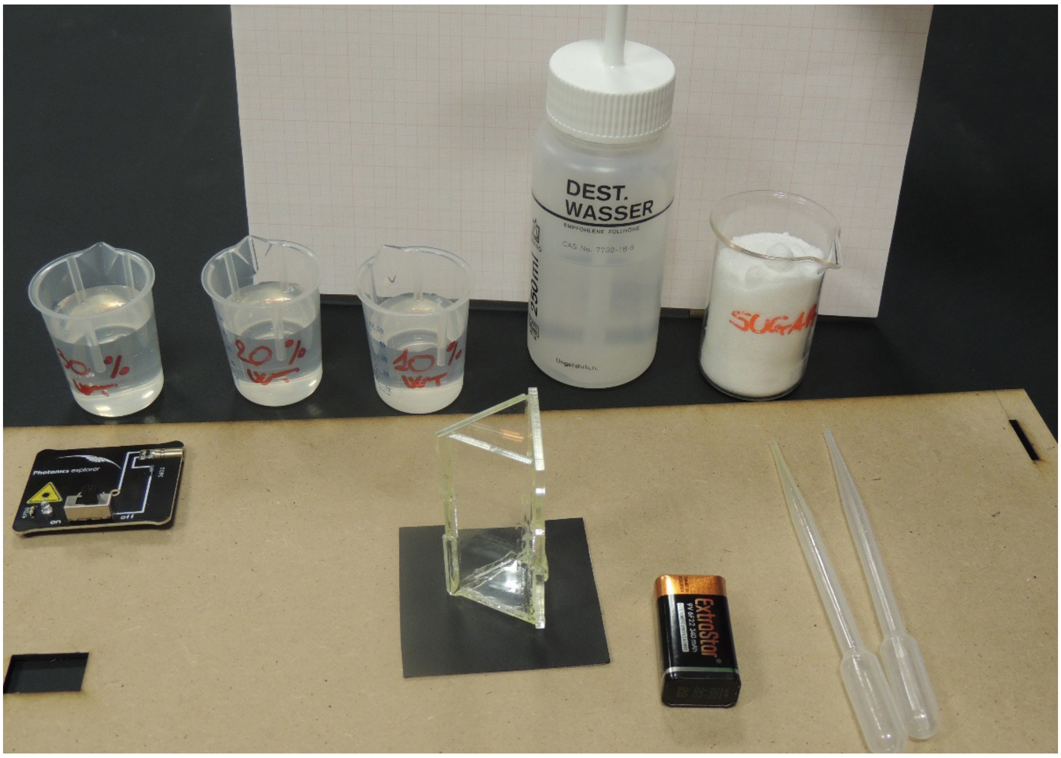


Figure 2.2: List of the materials: Sugar solutions (30%wt; 20wt%; 10wt%), distilled water, graph paper, MDF sheet (for realization of the “optical banch”), sugar, plexiglas sheet (for the realization of the hollow prism, glue, battery 9V and pasteurs pipettes.
The photonics parts can be bought by EYESTvzw.
The electronic parts can be bought by [Fablabfactory.](Fablabfactory)

Step 3: Fabrication

3.1 Fabrication of the hollow prism:

The fabrication of the hollow prism occurs using plexiglas sheet of the thickness of about 1-3 mm; cutted in proper shape using a laser cutter Legend 36EXT. (see file kitPLEXI.svg). The final result is shown in Figure 3.1 (Right).

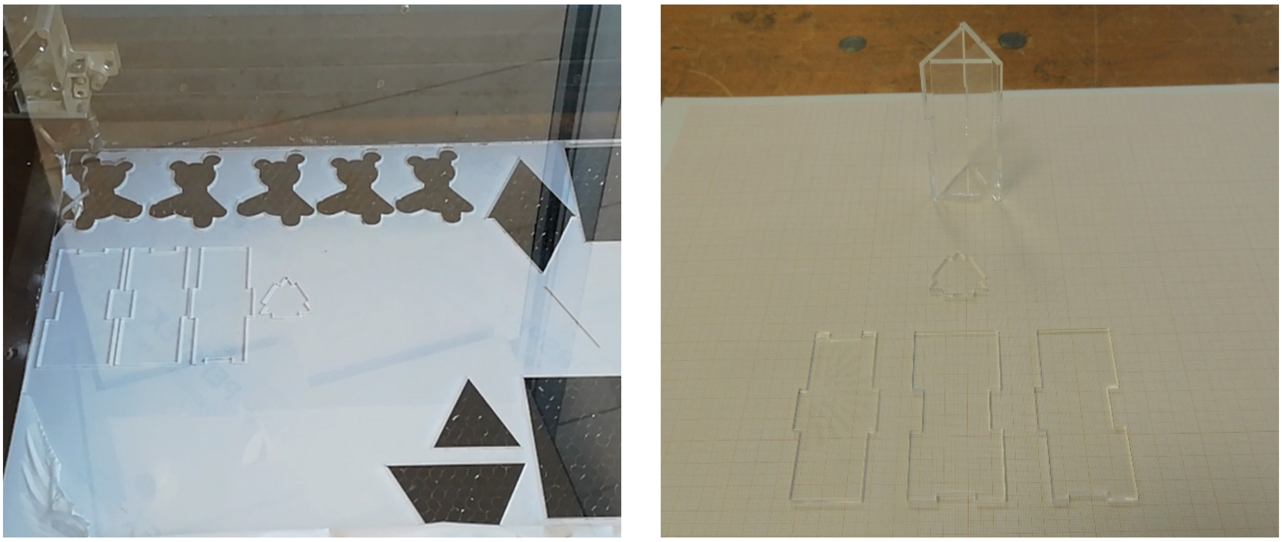


Figure 3.1: (Left) Overview of the definition of the prism elements after laser cut. (Right) 4 pieces for the realization of the hollow prism and the hollow prism assembled.

The assemblage of the hollow prism is based on the three steps reported in Figure 3.2. Initially the four pieces are put together finally glued in order to ensure a leak-proof hollow prism.

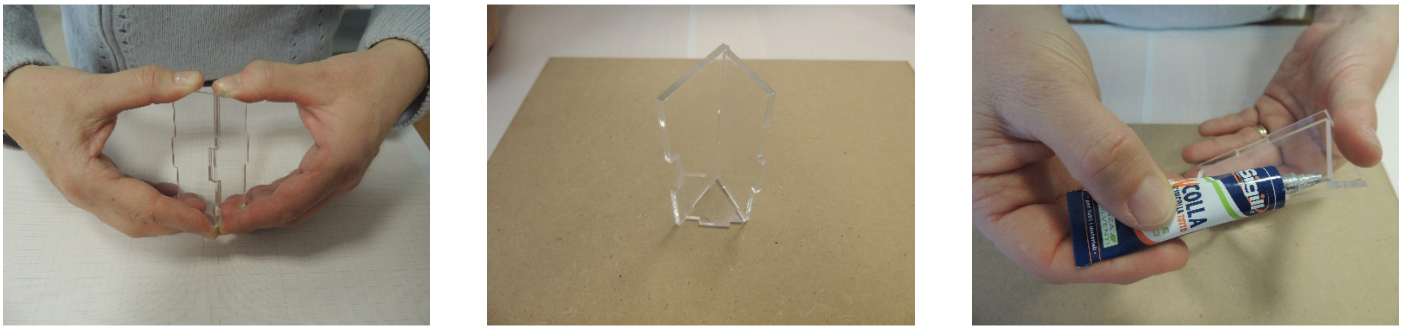
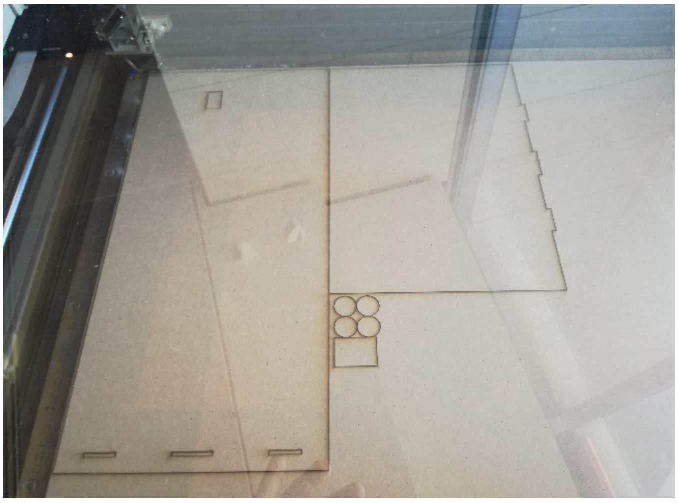


Figure 3.2: From left: The shaped plexiglas pieces are joined and finally glued.

3.2 Fabrication of the "Optical Banch":

The "Optical Banch" has been realized by using MDF as base material; for the screen, the basement for the positioning of the laser and screen, and the spacers. The screen has been covered with graph paper to measure the position of the spot of the refracted ray as a function of the different solutions.



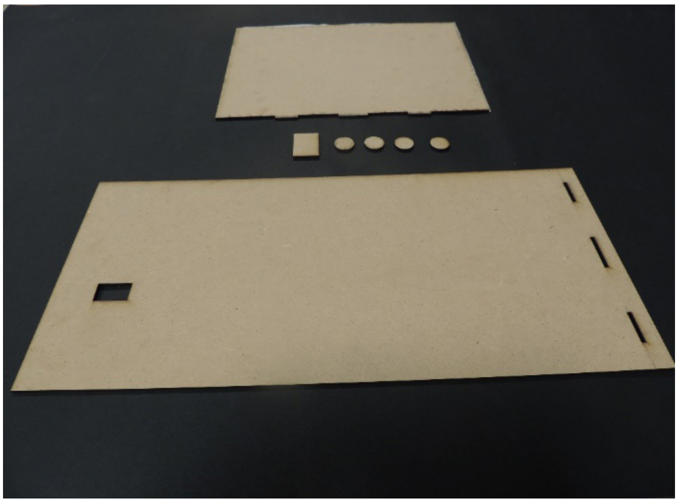
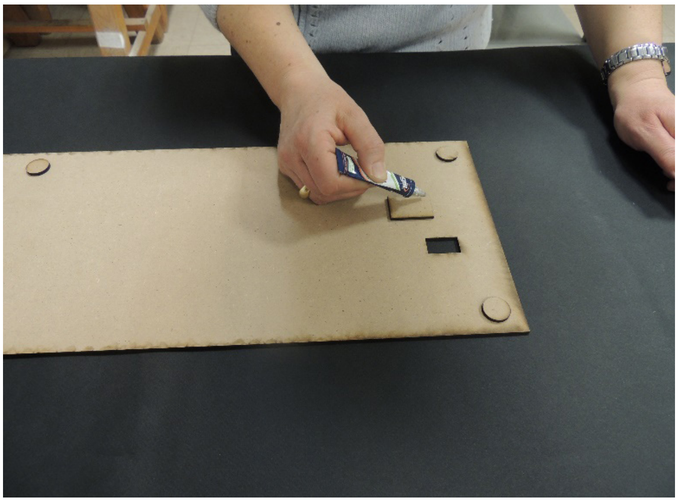


Figure 3.3: Overview of definition of the "Optical Banch" elements after laser cut. Detail of the (a) basement for laser and screen support, (b) spacers and (c) screen.

The elements reported, in Figure 3.3, have been obtained using the laser cutter Legend 36EXT (see file kitMDF.sgv)

It is important to fix the spacers with the glue as shown in Figure 3.4



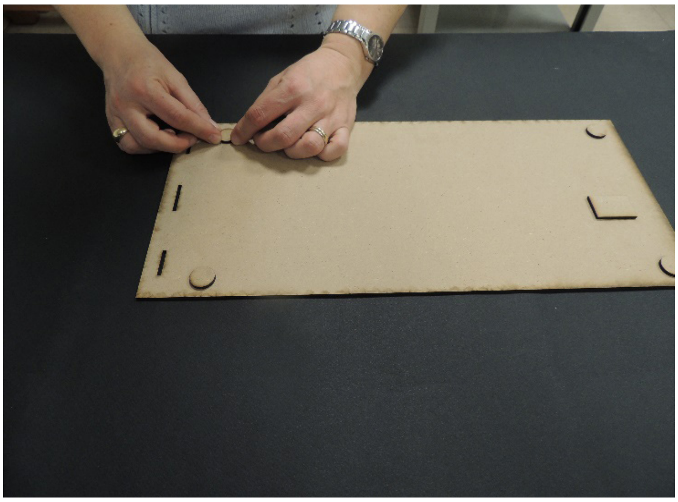


Figure 3.4: Two different moments concerning the placement of the spacers on the back of optical banch and their fixing by glue.

Overview of the mounted “Optical Banch”, with laser and hollow prism, is shown in Figure 3.5

Figure 3.5: Outline vision of the set-up mounted with the materials needed for the determination of sugar content.

Note: Three short videos have been realized in order to put in evidence the following points:

Fabrication of elements for the realization of the hollow prism (kitPRISM.mp4)

Fabrication of components for the “Optical Banch” (kitMDF.mp4)

Proof of concept of the experiment by using different solutions (distilled water, distilled water and sugar with the following concentrations 10%wt, 20%wt, 30%wt). (Experiment Proof of concept.mp4)

Step 4: EXTENSION

The improvement of this workshop can be obtained as following:

•For “young minds” a possible extension can be achieved combining the activity proposed by Ferdinand Braun Institute which proposed to build a polarimeter which can detect the concentration of sugar in a solution. In this case the students can address not only the concepts of reflection and refraction but also the polarization phenomenon.
Concerning the fabrication aspect is reasonable to think to use a 3D printer for the creation of the hollow prism. In this way the “young minds” can be aware of two different setups for the realization of photonic objects.

•Moreover young students could try to use the refractometer they have built at home, showing to parents and friends its working principle estimating for example the sugar content on some soft drinks as for example Sprite (it is colorless and the amount of gas is not disturbing the measurement since it vanishes in few minutes). As evidenced below there is good agreement between the calibration measurement using sugar and those obtained using a commercial drink such as “Sprite” (about 10%wt).
It is worth noticing that due to reduced power of the laser is necessary to employ not absorbing soft drinks; with a higher intensity laser is possible to estimate the concentration of the “Lemon or Peach Tea”

Step 5: Narrative Story

Prologue to the workshop.

We have found an important diary of Arthur Benjamin, whose nickname is "Uncle Ben". Uncle Ben moved to U.S.A. to work as a scientist. An editor friend of us looked at the diary and he was so excited that he offered to pay for its publication. The real problem is that some pages are missing, in particular, those related to the experiments. Therefore we decide to work together to try to complete it, becoming in this way co-authors of the book.

Diary part 1

My Dear Diary,
today the experiments were very satisfying! Today our first laser is arrived and its applications seems to be very promising. Alan, my assistant, is extremely enthusiastic and has got several ideas about its use. He would be really a perfect assistant, if he did not fall in love with Rosina, the responsible of the Chemistry's lab. Also yesterday, Alan fluttered his eyelashes at her and I'm sure that he will invite her for a dinner. Ah Rosina…….., I would like to invite her! But I feel inadequate. Moreover in this period I'm not in a good shape, in the last year I put on 6 kgs. On the contrary, Alain is in a perfect condition, damned Alain…….. Always smiling, always so ……. Suspect, because now I am realizing that he is the person who, unseen, prepares my tea in the morning and afternoon. I have no doubts: the only explanation to my belly fat must be a betrayal. I am quite sure that Alan adds sugar, kilos of sugar to my tea and my belly fat increases. I need to find the proper way to reveal the traitor……. I will ask Andrew, a long-standing friend, now working as a researcher in a famous scientific laboratory in Europe…… maybe he can give me some useful advices………

Now we explain to the students that Andrew's letter is missing, but we can find track of the answer in the others pages of the diary.

Diary, part 2

My Dear Diary,
The response of the balance is getting worst, but I have received an answer from Andrew. The positive news is that is extremely confident to manage to measure the sugar concentration in drinks exploiting……. light! He has not yet clear ideas, but he has an inspiration. He also gave me some tasks to do, that in his opinion, we can address using only our laser. He asked me to reply to the following questions:

- What happens to the light when it interacts with a glass or with some liquids?
- How can I bend the light as I wish?

Now I start immediately with the experiments: my belly fat is increasing and Rosina is becoming more and more beautiful.

The aim of this part is the familiarization of the students with the concepts:

- reflection (mirror);
- transmission (plexiglass);
- diffusion (white surface);
- absorption (black surface)

How do lasers work?' The young students are asked to answer; then the working principle of the lasers are explained them in a simple way (monochromatic light beam). A nebulizer is used to spray water into the air and show the path of light: it is pivotal to note that, in case of the undisturbed

beam, the light travels in a straight line.
The following material is given to each group:

- laser
- mirror
- plexiglass sheet
- white surface
- black surface

It is recommended to handle the laser with the extreme caution.
'How does light behaves when it interacts with mirrors, surfaces and transparent materials?'
The students must get to define the aboving concepts:

The aim of this part is the familiarization of the students with the concept of refraction:

The following items are available for each group:

- 1 glass
- water
- 1 teaspoon

The young students note that the immersed part of the spoon looks being raised and bent. This is the effect of refraction.
What happens when light travels from one medium to another? The students shine the laser into the water glass at one selected angle. They note that:

- the ray of light gets diverted (refracted) by the water;
- part of the ray is reflected;
- the intensities of the reflected and refracted rays depend on the incidence angle;
- the ray can be confined in the glass for selected incidence angles.

The students know from the previous experiment that transparent materials can refract light and the angle of the refracted ray depends on the materials.
In order to complete what it is described in the diary of Uncle Ben, one thing is still missing: the sugar. In order to perform some experiments, we need also to know the diameter and the volume of the glass. The sugar quantities can be determined by means of a weight scale.

By adding the sugar to the water in the glass, it is worth to be noticed that:

- the sugar allows to see the laser beam;
- the angle of refraction depends on the sugar concentration.

My Dear Diary,
Andrew was excited about my answer! However, he asked me to perform some strange measurements by using an object that didn't even know I had in the laboratory: the hollow prism. I never understood what it is for and how it works. Anyway, the night brings counsel. I'm going to drink a tea, I will write tomorrow.

Diary, part 3

My Dear Diary,
my suspicions about Alan are increasingly founded: yesterday he said me that I'm out of shape and he proposed to me to run together... AH! Unfaithful!! I know, my big belly is his fault! He is always in perfect shape despite all the tea that I offer to him. In any case, the correspondence with Andrew

is always fruitful. Today he sent me the project about the so-called “refractometer”. I am excited about the idea. He wrote to me: “According to my studies of chemistry, substances dissolved in water increase the refractive index of the solutions: the more the concentration increases, the more the refracted ray is deflected. I will send you the instructions to build a “refractometer”: you can measure the refractive index of specific concentrations and derive a calibrated scale. You can test your drink by observing the refracted ray of a laser through it: thanks to this tool it is possible to find out how much sugar your assistant put in your tea!
He suggests to perform a proof: check the effect by slowly adding the sugar to the solution! The projects look promising, I'll get to work on it.

The basic components for the refractometer are given to the students:

- plexiglas pieces (3 rectangles, 1 triangle) for building the prism;
- paper tape;
- sealant glue.

The three plexiglas rectangulars are sticked together with paper tape to form a prism. The sealing glue seals the corners. The plexiglas triangle is placed as base of the prism and sealed.

The following items are also provided:

- graph paper;
- MDF vertical supports for graph paper;
- ruler.

The students already have the laser with holder and battery.
The laser is pointed towards the graph paper mounted on the vertical support. By placing the prism along the path of the laser, the deviation of the beam can be estimated.

The students build the calibrated scales for 4 target concentrations (one for becker, the first must be zero): well defined sugar quantities are dissolved in water, then the solutions are mixed in order to get homogeneous liquid. The prism is filled with the solutions for testing by using the pipettes. Then the students look as the sugar concentration changes the angle of refraction of the laser and mark the results on the graph paper!

A solution with unknown concentration is given to each group: by using the reference scale, the student should be able to trace the concentration value of the drink prepared by the assistant of Uncle Ben.
N.B: Each glass is filled with the same amount of water. In this way the experiments of the group are compatible: we are measuring the concentration ….

Diary, part 4

My Dear Diary,
Andrew was right! The refractometer works.
What he couldn't predict was that Alan was in good faith. Damned!. After one week of analysis and a pound of flab on my stomach, I must admit. He never put more than 7 tablespoons sugar in my tea as usually I ask him! Actually, he put no more than 4, because I'm out of shape! And he, instead, goes to run every day! With Rosina! That's why he is so fit! And she also ... Dear Diary, I guess I'll have to going on a diet ...

Step 6: End result & conclusions

What we learned?

You learned to use your creativity to approach complex challenges, and exploiting the photonics, you can describe and address many curios aspects. You have dealt with several concepts that include chemical-physical parameters (solubility, concentration, refractive index) and with different phenomena (absorption, diffusion, transmission, reflection and refraction). Finally, you have realized your own instrument for the determination of the sugar concentration and understood his working principles..

Concluding thoughts

Refraction has many applications in optics and technology. A lens uses refraction to form an image of an object for many different purposes, such as magnification. A prism uses refraction to form a spectrum of colors from an incident beam of light. Refraction also plays an important role in the formation of a mirage and other optical illusions.

The refractometer is an instrument for the measurement of a refractive index and is often used in applications concerning quality control of raw intermediate and final products.

Laser Safety Rules

1.Act cautiously and responsibly! Do Not only think of your own safety but also that of others.

2.Never direct the laser beam or its reflection in anyone's face, including your own. Take precautions and think ahead to ensure that this cannot happen accidentally. Act responsibly!

3.The laser beam should always remain parallel to the table surface and must never leave the table boundaries. Make sure that the beam and its reflections are stopped before they reach the table edge. If an experiment really requires that the beam should leave the boundaries of the table, only one experiment at a time is allowed in the room and only under the teacher's supervision.

4.The laser itself, all components in the beam path and beam stoppers have to stand stable. Make sure of this before you switch on the laser. Anything that is easily tipped, like sod-- cover books or paper, are definitely not suitable as screen or beam stoppers.

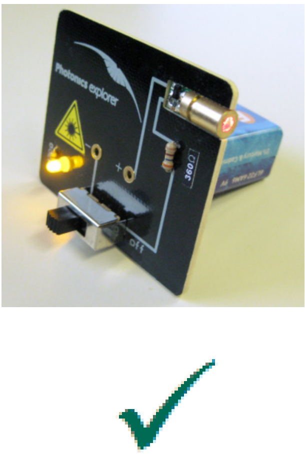
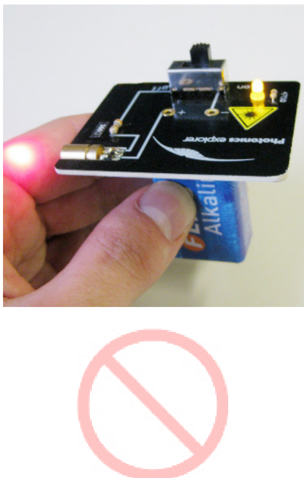
5.While the laser is on, the space within 10 cm above the table top is the laser zone. The laser beam and its reflections must not leave the laser zone! On the other hand, your eye absolutely must stay out of this zone– that is, in almost all cases, well above it. Don't forget this when you make a measurement and want to get a closer look! Also be careful if you 'just' want to get something out of your bag – beger check whether your neighbours really stopped their laser beams correctly before they reached the edge of their table. If you see someone else with his/her eyes to close to the laser zone warn him/her.

6.Before you switch on the laser, ensure that there are no reflective items in the laser zone: pack away things with metallic or reflective plastic surfaces, take rings off your fingers, do not use pens with metallic Aps to mark something on a screen, etc.

7.If you put anything into, or remove anything from, the laser zone – especially objects in the beam path! – make sure that reflections from their surface are always pointing downwards, towards the table.

8.If you see a laser beam or reflection of a beam on someone: warn him or her.

9.Act responsibly!


Annex

Concerning the realization of the hollow prism described in Section 3, this is a prototype. The assembly and gluing steps have to be carefully carried out to ensure the leakage-proof. For the correct realization of this type of workshop is fundamental to have a set of hollow prisms already available.

PHABLABS 4.0

PHABLABS 4.0 is a European project where **two major trends** are combined into one powerful and ambitious innovation pathway for digitization of European industry:
On the one hand the growing awareness of **photonics** as an important innovation driver and a **key enabling technology** towards a better society, and on the other hand the **exploding network of vibrant Fab Labs** where next-generation **practical skills-based learning** using KETs is core but where photonics is currently lacking.

www.PHABLABS.eu

This workshop was set up by the *Consiglio Nazionale delle Ricerche* in close collaboration with *MUSE FABLAB*.

CNR IFN Istituto di Fotonica e Nanotecnologie

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