Refraction: beyond fibre optics **by Julien Brousseau**

Physical sciences
Experiment
Junior Age 13
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Project summary

My research involved studying the prototype of a device that uses fibre optics to measure the index of refraction of various substances. This enabled me to automatically calculate the nature of certain substances, changes to these substances and their rates of contamination.

Project report

Fibre optics technology makes it possible to transmit data at the speed of light. It is a constantly changing field that is in full growth. It is impossible to discuss fibre optics technology without mentioning the advent of communications networks (e.g. the Internet) and the parallels that exist between the two.

After extensive research at the Standard Communications Laboratories in England, fibre optics has become very much in demand and is now used in almost every field. In addition to many others, it offers the following two main advantages:

1. Reliable signal transportation, even in high-voltage areas, since the electromagnetic impulses (interferences) do not result in any contamination.

2. Sensitivity to interference and signal detection

The major physics principle that inspired fibre optics technology is known as total internal reflection. This principle originates from the law of refraction, which states that a light ray crossing an interface between two media with different optical densities will be refracted, or bent. If the light ray passes from a more dense to a less dense medium, there is a minimum acceptance angle (the angle between the incident ray and the normal to the interface) at which the ray will not be refracted, but reflected. When the index of refraction of a dense transparent substance is higher than that of another substance, refraction—the change in direction or bending of the light ray—occurs.

For centuries, mathematicians tried to solve the mysteries of refraction. The law that best explains this principle is known as the Snell-Descartes Law.

The law can be stated as follows:

> "The product of the index of refraction (n_1) and the sine of the angle of incidence (sin<θ i) of a light ray, in a given medium, is equal to the product of the index of refraction (n_2) and the sine of the angle of refraction of the second medium (sin<θ r)."

The formula: $n_1 \sin{<}\theta\ i = n_2 \sin{<}\theta\ r$

I decided to devote my research to the study of a device that uses fibre optics to measure the index of refraction of various substances. This device, based on the Snell-Descartes Law, enabled me to identify the nature of substances used, as well as their rate of change through contamination (e.g. dilution). In order to measure these different factors, the light ray passing through the device is either contracted or dispersed, then measured.

Hypothesis

In the first experiment, I assume that paraffin can be used, since it is transparent and viscous (dense).

In the second experiment, I assume for the same reasons that glycerine can also be used. I use it with different percentages of contamination.

Materials

Throughout the project, I used the following instruments belonging to the department of physics of Cégep François-Xavier-Garneau: a stand, two multimode optical fibres (60 cm each), one HeNe laser (1.3), a microscope lens (10X), two sensors, six mounts with three translation axes, five special alignment mounts, an optical bench, a beaker, a graduated cylinder and a flashlight.

Experimental protocol

1. Install the optical bench on a very stable table.
2. Carefully insert the optical fibres in the special mounts, 1.35 mm apart.
3. Attach the stand, the sensor and the laser to the platform with two-way adhesive.
4. Activate the laser.
5. Affix the microscope lens to the front of the laser.
6. Align the laser and the optical fibres.

7. Test the index of refraction of the air before placing a liquid in the stand.
8. Prepare various glycerine and water concentrates (20%, 40%, 50%, 60% and 80%). Use a 20-mL beaker to facilitate the calculations (e.g. for a 20% glycerine concentrate, dilute 4 mL of glycerine with 16 mL of water).
9. Place water in the stand and observe the results obtained. Record the results, which will be used to calibrate the sensor, before changing substances.
10. Place a substance in the stand.
11. Darken the room. Use the flashlight to read and note the results appearing on the sensor dial.
12. Remove the liquid from the support and recalibrate the sensor with water, using the results obtained in step 9.

    Note: Clean the syringe after each use to reduce the risk of error.

Results

Experiment 1			
Photometric readings in luxes			
Medium	Ratio (%)	Index of refraction	Reading (luxes)
Air		1	0.8
Water		1.33	2.4
Paraffin	100		15
Propanol	100		1
Water and sugar			1
Vinegar	100		2.3

<table>
<tr><td colspan="4">Experiment 2</td></tr>
<tr><td colspan="4">Photometric readings in mV</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Medium</td><td>Ratio (%)</td><td>Index of refraction</td><td>Reading (mV)</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Air</td><td></td><td>1</td><td>16</td></tr>
<tr><td>Glycerine/water</td><td>0</td><td>1.33</td><td>114</td></tr>
<tr><td></td><td>20</td><td>1.36</td><td>143</td></tr>
<tr><td></td><td>40</td><td>1.39</td><td>202</td></tr>
<tr><td></td><td>50</td><td>1.40</td><td>206</td></tr>
<tr><td></td><td>60</td><td>1.41</td><td>210</td></tr>
<tr><td></td><td>80</td><td>1.44</td><td>220</td></tr>
<tr><td></td><td>100</td><td>1.47</td><td>232</td></tr>
<tr><td>Varnish thinner</td><td></td><td>1.36</td><td>200</td></tr>
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The following is a sample calculation based on the theoretical index of refraction of water and that of glycerine.

Procedure to follow:

Example: η glycerine – η water = 1.47 – 1.33 = 0.14

Percentage of concentration x difference in η water and η glycerine

0.2 x 0.14 = 0.028

η water + 0.028 = 1.33 + 0.028 = 1.358

Round off 1.358 to the nearest hundredth = 1.36

Discussion

This device makes it possible to obtain results that are consistent with those previously identified in the protocol chart for the substances observed. When examining the results obtained for glycerine in graph form, for example, we immediately notice that saturation occurs with concentrations greater than 50%.

Because a different sensor was required for the second experiment, the results obtained for propanol, vinegar and paraffin were measured in luxes, which involved very complex calculations when it came to converting to mV.

The varnish thinner created problems that forced me to discontinue my experiments. The substance pierced a plastic vial and melted my stand, causing it to leak. I was forced to stop my experiments following this incident, since the stand was no longer effective, preventing me from obtaining accurate results. During the experiments, the distance between optical fibres was 1.35 cm. I assume that changing the distance between the two fibres would result in different photometric readings, in accordance with predictable mathematical ratios (the greater the distance between optical fibres, the greater the dispersion of light between the two fibres, resulting in a greater decrease in the light ray entering the second fibre.

Conclusion

These experiments enabled me to observe that this type of device makes it possible to identify the presence of a given substance and determine the percentage of contamination required to modify it, using the substance’s theoretical index of refraction. Next year, I plan to develop a device that uses fibre optics to identify, at various levels, the presence of a substance and its level of contamination within a tank containing kerosene or another hazardous, inflammable or toxic product.