

CUDOS CHALLENGE

The CUDOS challenge is awarded annually to an individual student or to a group of students who demonstrate ingenuity and creativity within the framework of CUDOS research themes.

This year CUDOS has partnered with The Optical Society (OSA) to offer a unique opportunity to all CUDOS students and early career researchers. The challenge is to renew the international educational resource “*The OSA optics discovery kit*”. The winners of the 2015 challenge will contribute to optics outreach on a global scale, gain international visibility, and will be acknowledged in the OSA optics discovery kit.



2015 Challenge: OSA Optics discovery kit renewal

The OSA optics discovery kit is supplied to schools, teachers and students around the world through outreach programs. It contains a variety of optical components and detailed instructions that aim to introduce students to modern optical science and engineering.

Last year, prior to the CUDOS Photonics Showcase, the CUDOS outreach team in Sydney added two suggested experiments to the kit: The Herschel experiment, demonstrating that IR radiation exists, and the numerical aperture experiment, whereby the refractive index difference between the core and the cladding of a fibre can be determined. These experiments have already greatly enhanced the kit, as they are more sophisticated and interesting than the standard suggested experiments. During this process, the team discovered that the fibre which was provided with the kit was of such low quality that it was unsuited for all but the most elementary experiments. Therefore the fibre was replaced by a commercial grade fibre that was purchased specifically for this purpose. Additionally, an inexpensive laser was added to the kit.

The 2015 CUDOS challenge is aimed to further extend and enhance the experiments that can be done with the optics discovery kit. Thus, your task in this challenge is to devise one new experiment using the existing optical components or, if really necessary, including new, inexpensive optical elements that could be added to the kit to enhance outreach demonstrations.

To prepare for this student challenge, every CUDOS node will have access to a copy of the current discovery kit through your local Education & Training & Outreach Committee member (see below).

Guidelines

- Entries will be accepted from all CUDOS or CUDOS affiliated postgraduate students and early career researchers (ECRs).
- For the purpose of this challenge, an ECR is defined as a researcher who has been awarded a PhD on or after 1 January 2010.
- Entries will be accepted from individuals or teams.
- Each person can be named on a maximum number of 2 entries.
 - The experiment must demonstrate an aspect of optics or photonics that is interesting and understandable by school students (aged 10+).
- If additional components need to be purchased, the total costs must be below \$30.- per entry.

Expenses incurred in the purchase of additional components will be reimbursed by CUDOS Administration on submission of receipts.
- Entries must include a PDF file that clearly describes the experiment (including diagrams or photos) and also provides an explanation of the phenomenon for teacher use. Additional submission of a video file that shows the experiment is optional.
- Entries must be submitted via email To Ms. Shelley Martin, Centre Manager
(shelley.martin@sydney.edu.au).
- Closing date is **FRIDAY 30th JANUARY 2015**.
 - The total prize pool available for this year will be \$3,000 with a minimum of \$1,000 awarded to the winning entry/entries.
- The panel reserves the right to not award any prize.
 - All entries will be presented at the 2015 annual CUDOS Workshop and the winner(s) will be announced at a prize giving ceremony during the workshop dinner.

Judging Criteria

A panel will select the winner based on the following criteria:

- The Wow-factor: The experiment makes the students feel excited and surprised when first seen.
- Relevance: The phenomenon that underlies the experiment is of relevance for a student's understanding of optics and photonics.
- Clarity: The description of the experiment and the explanation of the phenomenon are clear and easy to understand.

Terms & Conditions

A condition of entry into the Challenge is that you give permission for CUDOS (headquartered at the University of Sydney) to use the experiment, optical components and description in a variety of media for outreach purposes. Note that by submitting an entry, you have assigned copyright of your entry to CUDOS. By entering you have also acknowledged that your entry may be made public on the CUDOS website, and may form part of the CUDOS online repository of good practice in outreach.

Enquiries

Any questions about the prize in general can be directed to Alex Fuerbach (alex.fuerbach@mq.edu.au) or Shelley Martin (shelley.martin@sydney.edu.au). Any

questions about technical specifications of the optics kit can be directed to Alvaro Casas-Bedoya (a.casas@physics.usyd.edu.au).

Education & Training & Outreach Committee

Alvaro Casas-Bedoya, University of Sydney

Benjamin Cumming, Swinburne

Judith Dawes, Macquarie

Kokou Dossou, UTS

Alex Fuerbach, Macquarie

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3D VIRTUAL REALITY WORLD

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Centre for Ultrahigh bandwidth devices for Optical Systems (CUDOS), The School of Physics, The University of Sydney



Outline

Most people think you need a special TV and glasses to see 3D movies.

Not true!

With the CUDOS Discovery Kit you can turn images into 3D, play interactive games on your phone, make your own 3D pictures, and understand the optics that makes this all work!

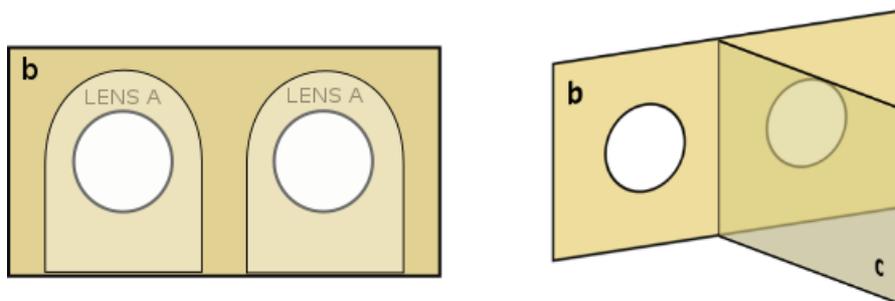
Apparatus

- Cardboard Goggles (included)
- Two Plastic lenses (included)
- Sample 2D image (included)
- Your Smartphone

Method

1) Build the Viewer

There are three cardboard cut-outs inside the Discovery Kit. Locate and cut out B and C. Attach two "Lens A" to cut-out B as shown below, in order to make the Viewer. Also attach the cut-out C perpendicularly to the Viewer using tape or blue-tack as shown below.



2) Check Viewer using sample image

Believe it or not, this is already enough to start seeing 3D with standard 2D pictures! There is a sample image inside the Kit, hold this at roughly the focal distance from the Viewer and at the correct distance,

as you look through the viewer the image should now look 3D! (Explanation of this effect is in the

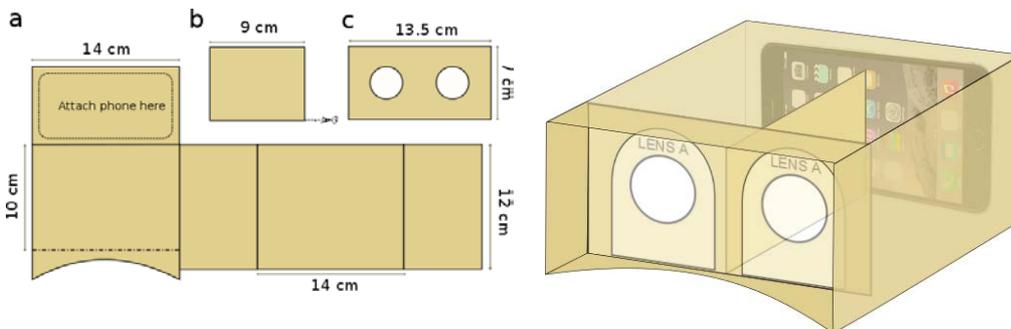


Background)

3) Building the Virtual Reality goggles

We can now extend the viewer to a virtual reality device using your smart phone. The cardboard cut-out “a” forms a box around the viewer in the previous step.

Now fold cut out “A” into a box, and insert the Viewer along the dotted line, making your 3D goggles. The final design should look like this:



4) Download Google Cardboard

There is a free app called Google Cardboard which takes advantage of this effect. It splits the screen into two images, which the viewer will give you the illusion of a 3D image. It also incorporates the motion tracking of the smart phone so you can look around and have a virtual reality effect!

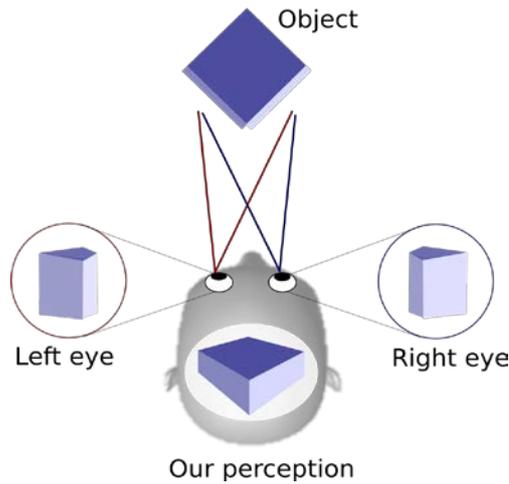


Background

The question to ask is “Why do we even see three dimensions in the first place?”

Our eyes measure colours and brightness but one eye cannot measure distance. In order to get a depth perception we use a technique known as *triangulation*, which works as follows. Our eyes are separated by some 5~10 cm so each eye sees a slightly different image of the object we look at (slightly

from the left, and slightly from the right). Because we have two images and a known distance between our eyes, our brain can stitch these two images together and give us depth perception.



The 3D goggles do exactly the same thing. There are two images displayed on the panel, each one taken at slightly different angles. To get a 3D effect we must make sure the left eye sees the left image, and the right eye sees the right image. The lenses are positioned such that each eye sees exactly one image each, which our brain interprets as a 3D image.

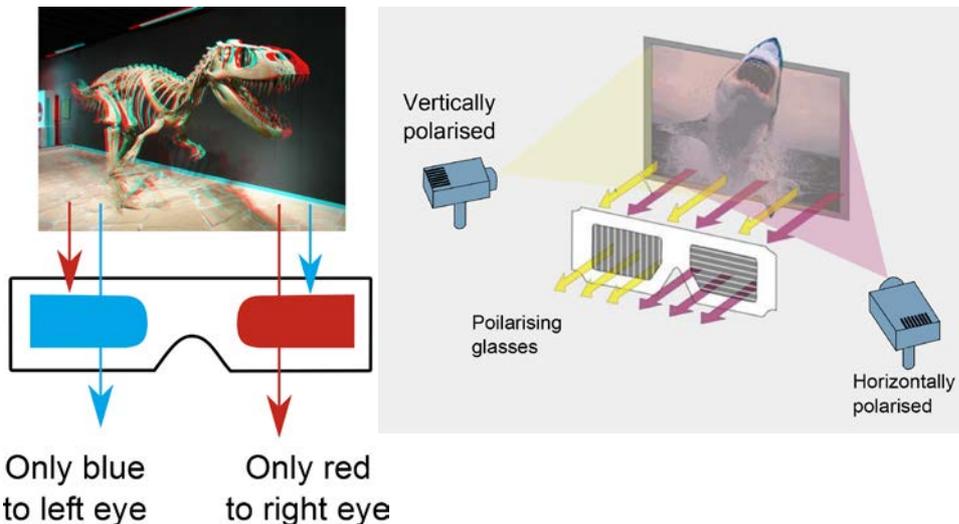
There are other 3D images that use this very same concept.

Using colour filters

Earlier ways of making 3D effects used red and blue images (taken from different angles) and using colour cellophane filter glasses so that each eye only sees one colour, giving a 3D effect. There is an obvious limit to what colours can be used however...

Using polarisation of light

Today we make 3D movies using *polarisation of light* (see experiment "Polarisers"). When we watch a movie there are actually two projectors which project the two screens filmed at slightly different angles. Each film has opposite polarisations and these can be filtered using polarising glasses, once again so that each eye sees only one image. The advantage here is there is no limit to the colours we can use, and this is what is happening when you watch a 3D movie!



Note: If you close one eye while watching a 3D movie, you'll see a regular 2D movie since you are only seeing the screen from **one** projector!

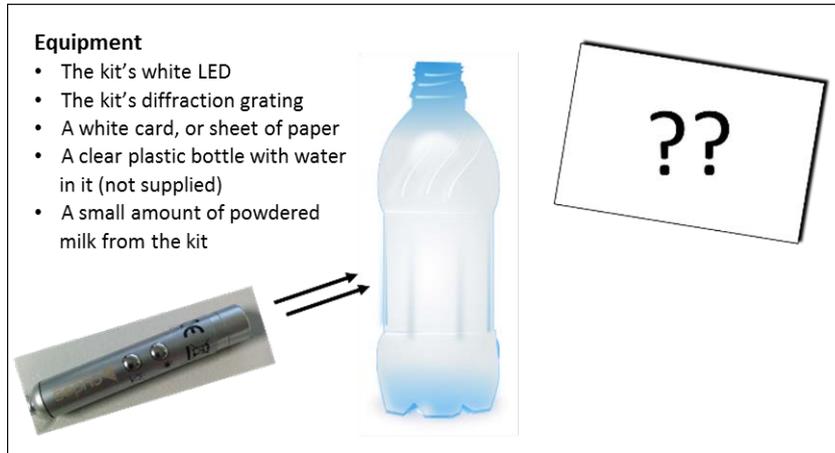
Brilliant Blue Bottles

Contributors 'Luke Helt' <luke.helt@mq.edu.au>

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Outline

Have you ever wondered “why is the sky blue?” It’s not that sunlight is blue, nor is it that there’s blue dye in the atmosphere. The sky is blue due to a phenomenon called *Rayleigh scattering*, and in this experiment you’ll demonstrate how it works for yourself!



Things To Do

Shine the LED on the white card directly. Shine the LED on the white card through the diffraction grating.

Q1 What colour(s) do you see on the card when the LED shines on it directly? What about after the LED light has passed through the diffraction grating?

Shine the LED on the card through the bottle. Add a small amount of powdered milk to the bottle and repeat.

Q2 What colour(s) do you see on the card before the powdered milk has been added? What about after it's been added? What colour is the liquid in the bottle? Why?

Q3 What colour does the sun appear when viewed from outer space?

How Is This Useful?

Although light from the sun, a flashlight, or the kit's LED can all appear white, their light is actually made up of many colours or *wavelengths*. You may have seen these colours split apart by a prism or by raindrops as a rainbow.



But there is (at least) one other way for the wavelengths making up white light to be split apart, and it can do so even more strongly than a prism or raindrops can. When light strikes molecules, it has a chance to bounce off of them in all directions or *scatters*. Different wavelengths have different probabilities of scattering.

Blue wavelengths are more than 3x as likely to scatter off of really small molecules in the atmosphere as red wavelengths. The blue light, going in all directions, makes for a blue sky while the red light, travelling more or less straight, makes for a red sunset. This phenomenon is known as Rayleigh scattering, and you can demonstrate it yourself in a clear plastic bottle. There are many gas molecules suspended in the Earth's atmosphere for sunlight to scatter off of, and a bit of milk suspended in water in a clear plastic bottle mimics this aspect of the atmosphere in a much smaller space quite well.

Teacher Notes

To make the colours more visible on the white card it may be preferable to perform this experiment in a dimly lit room.

For the mathematically curious, Rayleigh scattering is essentially the absorption and reemission (in all directions) of incident light by the electrons of gas molecules. If these electrons are modelled as harmonic oscillators and the incident wavelength is well above their resonant wavelength, both the scattered electric and magnetic fields can be shown to be proportional to $1/\lambda^2$ in the far field. As light intensity is proportional to their product, the intensity of Rayleigh scattered light is proportional to $1/\lambda^4$.

The estimate of blue light being more than 3x as likely to be scattered than red light was obtained by comparing $1/\lambda^4$ for $\lambda = 620$ nm (red) and $\lambda = 450$ nm (blue). Different estimations are possible depending on the definition of red and blue wavelengths.

While one might know that violet wavelengths are even shorter than blue wavelengths and thus think that the sky should appear violet, it doesn't because 1) the sun doesn't emit as strongly in the violet as in the blue and 2) because our eyes aren't as sensitive to violet light as to blue.

A1 From experiment #7 and upon shining the LED on the card through the diffraction grating, it should be clear that the white light of the LED contains all of the colours of the rainbow (blue, green, yellow, orange, and red).

A2 As mentioned above, the milk suspended in the water mimics the gas molecules suspended in the Earth's atmosphere. The water itself doesn't change the colour of white light, Rayleigh scattering by the suspended milk particles does. The light that scatters is blue and lights up the bottle while the light that emerges from the bottle is orangey-red, like a sunset. Note that the light emerging becomes yellower as it passes through less of the liquid and redder as it passes through more.

A3 With no particles to scatter off of, light from the sun in outer space appears white.



Herschel Experiment

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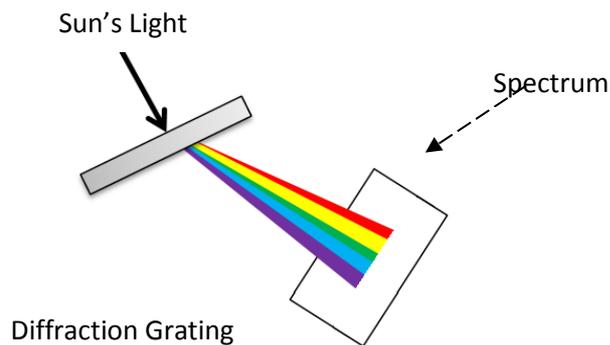
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Outline

This demonstration investigates the electromagnetic spectrum beyond visible light and demonstrates one method of identifying the existence of invisible light. Students use a grating to separate out (or *diffract*) the light emitted from the sun into a spectrum. Following this, through using a precise thermometer placed just beyond the red diffracted light, students are able to obtain proof of the existence of infrared light by observing the temperature indicated on a thermometer. This experiment is best carried out in small groups of 2-3 students and it is important that the experiment be conducted in direct sunlight on a clear day.

Apparatus

- A precise thermometer (capable of resolving 0.1°C for best results)
- Black paint or a black permanent marker
- A diffraction grating (supplied)
- A cardboard box or similar item to provide shade for the thermometer

Method

- 1) Paint or colour the thermometer bulb black. Why do you think this is required? When the paint/ink is dry, place the thermometer in a shaded area and record the temperature. All measurements should only be recorded when the temperature shown on the thermometer is no longer increasing/decreasing.
- 2) Place the diffraction grating between the sun and a white sheet of paper, the grating should diffract the sun's light onto the sheet of paper so that a spectrum of coloured light is visible, you may need to adjust the placement of the grating and sheet of paper.
- 3) Place the thermometer on the sheet of paper such that its bulb is in the 'blue' section of the diffracted light, record the temperature. The grating will need to be in direct sunlight for this, however, be careful to make sure that the thermometer is **not** in direct sunlight, e.g. by using a cardboard box or similar to provide shade.
- 4) Repeat step three while placing the thermometer in the yellow and red sections of the diffracted light, and again with it *just* beyond the red section, where there is no visible light. What do you notice about your temperature readings? Do you observe a trend? If you observe any heating of the thermometer just beyond the red section, why do you think this is?

Results

The bulb of the thermometer was blackened so that it would better absorb the energy carried by the sun's radiation and heats up. The highest temperature will be obtained in the red (or just beyond) light. The exact temperature values vary with the time of day and distance to the grating; however, you should observe an increase in temperature from the 'blue' measurement to the 'red' measurement.

All four values will be above that of the temperature of the shade. In particular, the temperature measured in the region just beyond red (called the *infrared* region) will be higher than the temperature measured in the shade.

Discussion

The heating of the thermometer in the infrared region is due to the sun emitting invisible infrared light at longer wavelengths than visible light. Visible light is actually only a very small portion of the '*electromagnetic spectrum*' of radiation; there exist many different types of light, which we cannot see. Herschel's experiment, carried out in 1800 using a prism instead of a grating, was important not only because it led to the discovery of infrared light, but also because it was the first demonstration proving that there were forms of light that you cannot see with your eyes. In fact, some animals can actually see this type of light, often using infrared vision to sense other animals. This allows Boa Constrictors and Pit Vipers to strike with deadly accuracy, Piranha's use infrared vision in murky waters (where visible light is scattered) and mosquitoes use it to locate blood rich regions of the body. Today, infrared light is used in medical procedures, for non-invasive imaging, as well as areas such as police and security work and military surveillance. Infrared cameras even allow fire fighters to locate 'hot spots' caused by people and animals caught in heavy smoke.

Optical Fibre Numerical Aperture

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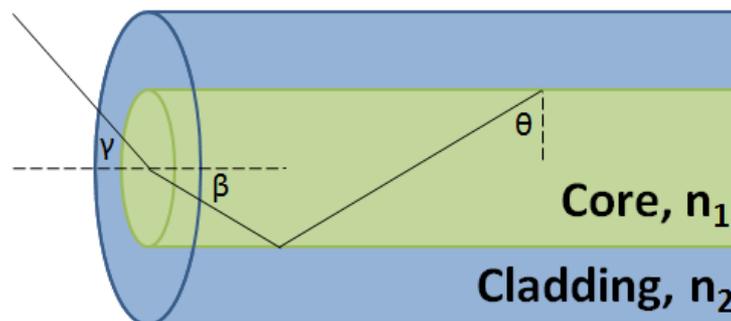
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Centre for Ultrahigh bandwidth devices for Optical Systems (CUDOS), The School of Physics, The University of Sydney



Outline

All phone calls, all web downloads, in short, any telecommunication information, is transferred over long distances in the form of short optical pulses travelling through optical fibres. Optical fibres consist of a core with a high refractive index and a cladding in which the refractive index is lower. The light remains in the core by total internal reflection, so it can be guided over large distances. The aim of this experiment is to estimate the refractive index difference between the core and the cladding of a fibre by measuring the angles at which light exits the fibre.

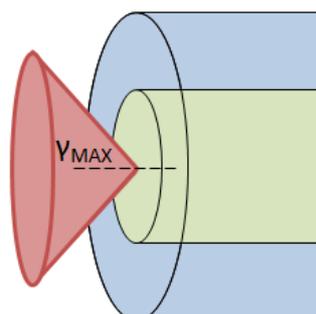
Background

The figure above shows a schematic of an optical fibre; it consists of a core with a cylindrical shape and refractive index n_1 , surrounded by a cladding with refractive index n_2 . For the light to remain in the core we must have total internal reflection and thus we need $n_1 > n_2$. From Snell's law we find that light incident on the interface with the cladding at angles θ with $\sin \theta > n_1/n_2$ undergo total internal reflection; light at smaller incident angles is lost.

Eventually the guided light makes it to the end of the fibre. Using the properties of triangles you can prove that because not all light is totally internally reflected by the cladding, light can only exit the fibre at angles γ which are smaller than a maximum angle γ_{max} (see figure below). The angle γ_{max} is such that $\sin \gamma_{max} = \sqrt{n_2^2 - n_1^2}$. Thus by measuring the maximum angle γ_{max} , we can relate the fibre's core and cladding refractive indices. The quantity $\sin \gamma_{max}$ is the fibre's *numerical aperture* (NA). It not only indicates the range of angles exiting the fibre, but also the range of angle required to couple into it.

Apparatus

- A piece of optical fibre (supplied)
- A strong torch
- A sheet of white paper
- A protractor
- A ruler
- A pocket calculator



Method

This experiment is most conveniently carried out by two people, however some handy folks could possibly do it on their own.

1. Shine the light from the torch into one end of the fibre; try to position it such that the light exiting the other side is as bright as possible;
2. Hold a piece of paper in front of the free end of the fibre. By using the paper as a screen and moving it closer and further away from the fibre end, observe a light cone exiting the fibre. Why do you think the light exiting takes the shape of a cone?
3. Put the free end of the fibre sideways on piece of paper and use the ruler and the protractor to measure the maximum angle.
4. Noting that γ_{max} is half of the vertex angle, use the pocket calculator find $n_2^2 - n_1^2$.
5. The core refractive index is $n_1 = 1.49$. This allows you to find the cladding refractive index n_2 .

Results

The light exits the fibre in a cone since a range of angles is totally internal reflected by the cladding (in fact for this fibre all rays which are incident at angles, θ , larger than 75°); therefore there is a range of angles incident on the fibre's end face (for this fibre the maximum angle is $90^\circ - 75^\circ = 15^\circ$). In the air this corresponds to a range of angles with a maximum angle, which can be calculated using Snell's law. The structure is unchanged when you rotate the fibre about its axis and so the light comes out in a cone with a vertex angle of $2\gamma_{max}$ (see the figure in part 1).

When you lay the fibre sideways on the paper you see a triangular cross section of the cone. Use the ruler to draw the side of the triangle and then the protractor to find the vertex angle $2\gamma_{max}$. You should find that the vertex angle of the cone is approximately 45° and so $\gamma_{max} = 22.5^\circ$, and the fibre thus has an NA of approximately 0.38. By using the relation between the NA the refractive indices we find that $n_1^2 - n_2^2 \approx 0.15$. This particular fiber has Polymethyl Methacrylate Resin (PMMA), also known as Perspex or Plexiglas, as its core material. PMMA has a refractive index of $n_1 = 1.49$, and so the cladding refractive is $n_2 = 1.44$. For these two refractive indices the total internal reflection angle is 75° since $\sin 75^\circ = 0.965 \approx 1.44/1.49$.

Discussion

This fibre is made of plastic, and is designed to be used to guide light over short distances, for example in homes or in hostile environments, or to light internal surgery. Standard, long-distance telecommunications fibre is made of glass and has a NA = 0.14. The cladding is made of silica glass with a refractive index of $n_2 \approx 1.47$. Thus the core refractive index is approximately $n_1 \approx 1.477$.

Note: One of the issues with optical fibres is that they need good cleaves. If you cannot see the cone well then use scissors to cut off a small length of fiber (1-2 mm) and then try again.

Appendix

Proof of the expression for the NA

Since $\sin \theta > n_1/n_2$ and θ and β are adjacent angles in a right triangle (see first figure in Part 1), $\cos \beta > n_1/n_2$. Because $\sin^2 \varphi + \cos^2 \varphi = 1$ for any angle φ we also have $\sin \beta < \sqrt{1 - n_1^2/n_2^2}$. But this is the angle inside the fibre core. Using now Snell's to find the angle in air (with a refractive index $n = 1$) we find for light within the exiting cone that $\sin \gamma < \sqrt{n_2^2 - n_1^2}$, and thus $\sin \gamma_{max} = \sqrt{n_2^2 - n_1^2}$.

Further discussion:

The NA of a fibre determines the sensitivity of the fibre to bend losses. If a fibre is strongly bent then total internal reflection may no longer occur, so the light is no longer guided in the core and is lost. The larger the NA, the more tolerant the fibre is to these *bend losses*. The plastic fibre used in this experiment has a large NA and is thus fairly robust against bend losses. In contrast, standard telecommunications fibre is much more sensitive and this often determines the minimum size of a fibre device.

In a standard fibre the cladding is made of silica glass (basically SiO_2). The core consists mainly of silica glass, but with some of the silicon replaced by germanium. Germanium appears below silicon in the

same column in the periodic table and it thus has similar chemical properties. However, it has more electrons, which raises the refractive index, which is exactly what is required to guide the light.

The plastic fibre has a core diameter of $980\ \mu\text{m}$ whereas in standard telecommunications fibres it is only $8.2\ \mu\text{m}$. You can imagine how hard it would be to couple light into such a fibre.

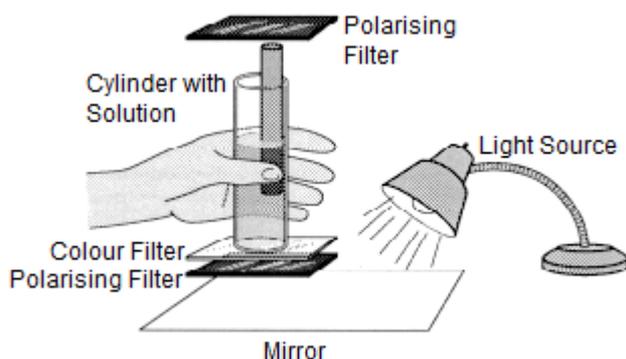
SPUN SUGAR: POLARISING SUGAR CRYSTALS

Contributor: BLAKE ENTWISLE <blake.entwisle@students.mq.edu.au>

Department of Physics and Astronomy, Macquarie University

Materials

- Two polarising squares (supplied)
- Colour filters (supplied)
- Sugar syrup *and/or* Sugar solution (use a single sugar type eg. Fructose, sucrose etc.)
- Cylinder for holding sugar solution
- White light source (supplied)
- Mirror (reflective silver sheet - supplied)



http://www.exploratorium.edu/snacks/rotating_light/

Things To Do

Begin by making the sugar solution to high concentration. Fill the cylinder most of the way to the top. Place the first polarising sheet at the base of the cylinder and the other sheet at the top of the cylinder. Have the white light source shining through the base of the cylinder. (A mirror may help achieve this more easily, else use an overhead projector as the light source).

E1 Now view the light passing through the top polarising sheet. As you slowly rotate the top sheet you will notice that the sugar solution/syrup changes colour.

E2 Next, keep the two polarising sheets in the same position and increase and/or decrease the amount of sugar solution. Again, you should be able to observe a change in the colour of the solution through the top filter.

E3 Try each of the previous experiments with the addition of a colour filter before the polarising sheet. Use the colours separately. Let's assume you've started with green. First rotate the filter to find the green colour. Next, measure how much a rotation it takes to view green again. Repeat with the other colour filters.

Q&A

Questions

Q1 Set the first position of the filter as 0° in **E1**. Spin the polarising filter through 360° , making a note of the angle at which the colour noticeably changes. Do the same for the height/volume of solution that causes a change in colour. Can you find a relation between height changes and a rotation angle?

Q2 Are all colours of the spectrum able to be seen?

Q3 Does the effect you see change with different sugars? Try honey, or a different type of sugar.

Answers

A1 The angle at which the colour change occurs will be different for each concentration. A stronger solution should have a more rapid change than a weaker one. However, there should always be a colour that is more dominant than the others. Certain rotations should also completely block out a particular colour.

A2 The results for this should be similar to those for rotating the filter. The exact depth at which changes occur again depend on the concentration of sugar.

A3 Some sugars will rotate the polarisation of light to the left, such as sucrose and glucose. Others will rotate it to the right, such as fructose (found in honey), so the effect may be reversed. This means the filter will need to be rotated right instead of left from the starting position in order to replicate the observed effects.

How Is This Useful?

We can use this effect to determine the structure of some materials. A chemical that circularly polarises light must have a “chiral” structure. We can determine a lot about this structure without an expensive, high power microscope by seeing what this chemical does to light. If you measure the concentrations accurately, you may also notice that fructose has a stronger effect than glucose at rotating the light. Scientists can use their knowledge of the properties of light to make measurements more easily or determine some of the basic properties of a molecule before needing expensive equipment.

How Does It Work?

White light from your lamp or from the sun is unpolarised. All light has a polarisation which is the direction of the light’s electromagnetic field that moves perpendicular to its direction of travel. This means light is a *transverse* wave. In unpolarised light, the orientation of this polarisation is random.

When light passes through a polarising filter, only light of a specific polarisation is let through – all the others are blocked. In unpolarised light there is a little of every polarisation direction, so some light always gets through a polariser, no matter which way you turn it.

Light passing through the sugar syrup is then rotated. However, this time, the wavelength of the light determines how much the polarisation of the light will be affected. Since all light went into the solution with the same polarisation, only the wavelength and strength of the solution will affect the output. Blue light bends more than red light as it has a shorter wavelength.

Interestingly, without the second filter, the light will still look white, as our eyes do not separate out different polarisations. So even though green may be horizontal, red vertical and blue diagonally polarised, our eyes still see white light. With the addition of the second filter however, only specific polarisation of light are allowed through. If only specific polarisations are allowed through, and each wavelength (colour) has had its polarisation changed by a different amount, the polarising filter will then only let through specific colours.