Global BioImaging Train-the-Trainer 2025 Course in Australia

Outline of the Demos of light-matter interaction carried out during the course – notes by Lía Pietrasanta (University of Buenos Aires, Argentina)

How Light Interacts with Matter

When light encounters different materials and surfaces, it can exhibit a variety of fascinating behaviours. These interactions are fundamental to understanding many natural phenomena and technologies. Light may **be reflected**, as in mirrors or the formation of rainbows; **refracted**, as it bends through lenses or water droplets; **absorbed**, which gives objects their colour and can generate heat; **transmitted**, allowing us to see through glass; **scattered**, which explains why the sky appears blue and clouds look white; **polarized**, as seen with polarizing filters; or **emitted**, as in fluorescence and lasers. Each of these processes reveals how matter can absorb, reflect, refract, or scatter light, leading to the creation of colours and images and enabling innovations such as solar cells and spectroscopy.

We will share some basic demos using the elements that we have in the laboratory.

A- <u>REFLECTION</u>

1. **Reflection**: is a process in which light **"bounces off"** a surface and **changes direction. There are two different types of reflection.**
    a. Reflection off an **extremely smooth surface** (mirror, a very still body of water, polished surfaces). Every time you look in a mirror, you see light reflected from the surface, producing a clear image of you and your surroundings.
    b. Reflection off a **rough surface** (a piece of paper). This type of reflection does not produce an image; it reflects in many directions because the paper's surface looks rough and uneven under a microscope.

Materials: Mirror, flashlight or laser pointer, a piece of paper.

Activity: Shine the flashlight or laser pointer at different angles onto the mirror. Observe the angle of reflection.

Setup & Procedure:

1. Shine the flashlight or laser pointer at different angles onto the mirror.
2. Observe the angle at which the light reflects.

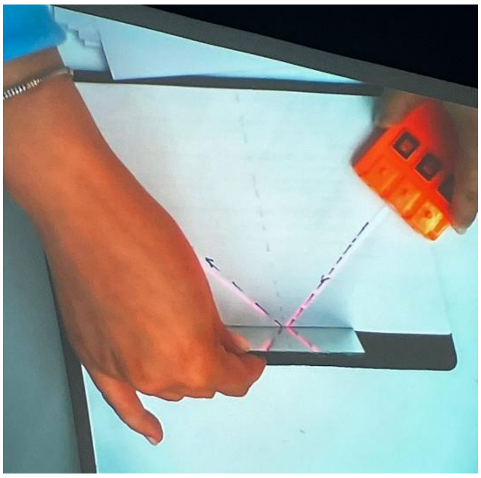
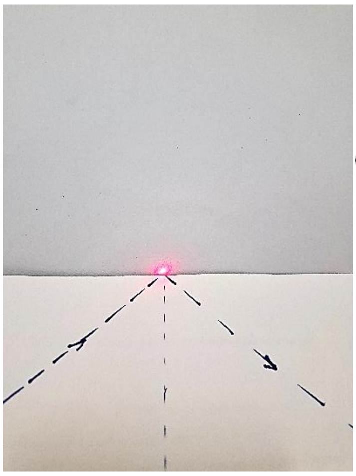
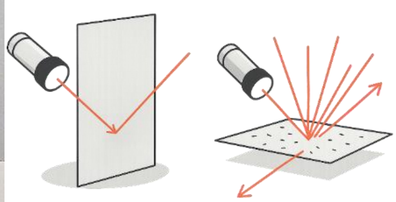
Observations:

- The angle of reflection equals the angle of incidence.
- On a piece of paper, a reflection does not produce an image; it reflects in many directions

Science Explanation:

When light strikes an object, it often just reflects from its surface. Light bounces off surfaces at the same angle at which it arrives. **This is called the law of reflection**.

Now, I would like to illustrate a specific case where **complete reflection** of a wave, most commonly light, **occurs within a medium**. This happens when light travels from a denser to a less dense medium at an **angle of incidence greater than the critical angle**. In this situation, all the light is reflected back into the original medium rather than refracted into the second medium.

2. **Total Internal Reflection**

Materials: Beaker, water, laser pointer

Activity: Fill the beaker with water and shine the laser pointer into the water at a shallow angle and observe the light reflecting inside the water.

Setup & Procedure:

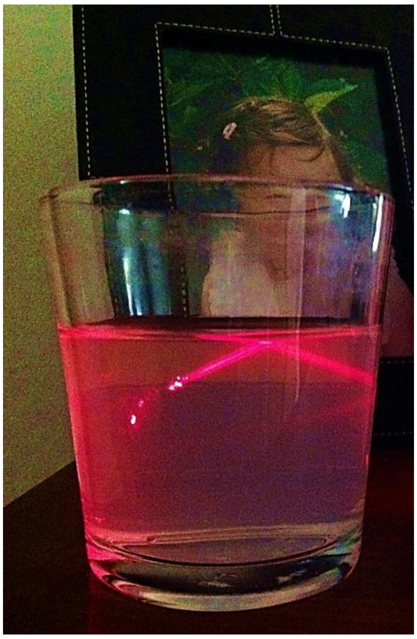
1. Fill the beaker with water.
2. Shine the laser pointer into the water at a shallow angle.
3. Observe the light reflecting inside the water.

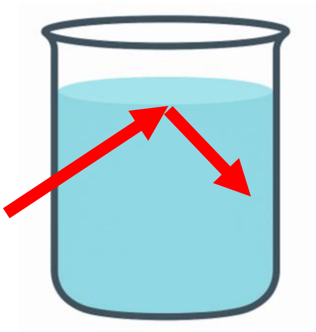
Observations:

- The laser beam reflects off the inside surface of the water, staying within the beaker.

Science Explanation:

When light travels from water to air at a shallow angle, it is reflected back into the water rather than passing through. This is called **total internal reflection.** It's the principle behind fibre optics, which transmits light signals over long distances.





B- <u>REFRACTION</u>

1. **Refraction** is the process by which light **changes direction** when it moves from one medium to another. **The path of light bends.** Bending of light due to a change in speed as it passes, **at an angle**, from one material to another. The two materials must have **different refractive indices** or **optical densities** for refraction to occur. Bending of light as it passes a corner, an edge, or through an opening or slit that is physically the same size or smaller than the wavelength of the light

Materials: beaker or glass, water, laser pointer, pencil, transparent material

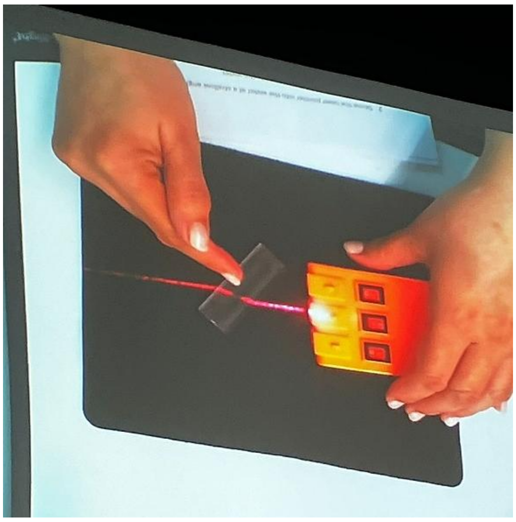
Activity: Laser Bending: Shine a laser through a transparent material at an angle and observe how its path changes. **Water Tank:** Place a pencil in a glass of water and observe how it appears bent at the water's surface. First, position it vertically, and it will look whole. However, when you tilt it, your brain perceives it as broken.

Setup & Procedure:

- **1- Laser bending**: Shine the laser pointer into the piece of transparent material at a shallow angle.
- Observe how the beam's path changes
- **2- Water tank**: Fill the beaker or glass with water.
- Place a pencil in a glass of water and observe how it appears bent at the water's surface.

Science explanation:

Refraction occurs because light travels at different speeds in different materials. Our brain assumes that light always travels in a straight line, so it has trouble determining the pencil's bottom position. That's why the pencil appears broken at the waterline.



2. REFRACTION and TRANSPARENCY: Disappearing Beads

I mention that refraction happens when two materials have different refractive indices. The refractive index of a medium is a measure of how much the speed of light decreases when light passes through it. To demonstrate this, we will use hydrogel beads and marble.

Materials: transparent beaker or glass, water beads (hydrogel beads, often used in floral arrangements), marbles, and water.

Setup & Procedure:

1. Place dry water beads in the beaker and observe their appearance. They should look small, hard, and opaque.

2. Add water to the beaker and let the beads soak for several hours (or overnight). The beads will absorb water and swell.

3. Once the beads are fully hydrated, fill the beaker to the top with water.

4. Observe the beaker from the side. Try to look for the beads inside the water.

Observations

- When dry, the beads are clearly visible.
- After absorbing water, the beads become much larger and almost transparent.
- When the beaker is filled with water and hydrated beads, the beads seem to "disappear"—it looks like the beaker is just full of water!

Science Explanation

This phenomenon is due to refraction and the **matching of refractive indices**:

- Light bends (refracts) when it passes from one material to another with a different refractive index.
- Dry beads have a refractive index very different from air, so they scatter and reflect light, making them visible.
- When beads absorb water, their refractive index becomes very close to that of water.
- If the refractive indices of the beads and water are nearly the same, light passes through both with slight bending and scattering. As a result, the beads become almost invisible in water. This is an excellent **demonstration of how materials can appear or disappear depending on their interaction with light.**

5. Refraction of Light with an arrow experiment (refraction of light in water)

Refraction of light causes arrows viewed through a glass of water to appear rotated or flipped because the water-filled glass acts like a convex lens, bending light rays inward and causing them to cross over, flipping the image's left and right sides, especially when the arrow is beyond the lens's focal point. Light bends as it changes speed, moving from air to glass, then water, and back, making the arrow's head and tail switch positions visually.

How it works

- **Bending Light:** When light travels from one medium (like air) to another (like water or glass), it changes speed and bends, a process called **refraction**.
- **Convex Lens Effect:** A round glass filled with water acts like a convex lens, focusing light rays towards a central point (the focal point).

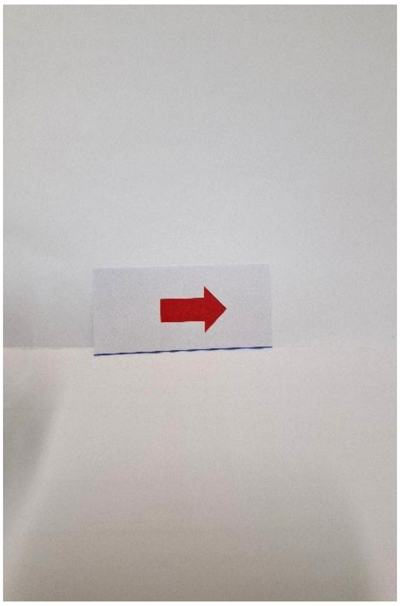
- **Image Inversion:**
    - Light rays from the arrow's tip bend towards the centre and cross over, appearing to come from the opposite side of the arrow.
    - Similarly, light from the tail bends and crosses over, appearing to come from the other side.
- **Distance Matters:** The image appears normal when close (before the focal point), flips when moved further away (past the focal point), and can change again with more distance, demonstrating the lens effect.

Simple Experiment

1. Draw an arrow pointing right on paper.
2. Place a glass of water in front of it.
3. Look at the arrow *through* the glass of water.
4. Move the paper/glass until the arrow appears to point left (flipped).

In simpler terms, the light coming from the tip of the arrow refracts on its way to your eyes, and instead of being on the right side, it is now on the left side.

If you move closer to the glass, you will notice that the arrow appears in the same direction as it is drawn on paper. This is because your eyes are now closer to the image than the focal point.




3- REFRACTION and DISPERSION

Materials:

- Prism
- Flashlight or laser pointer

Setup & Procedure:

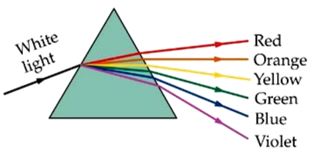
1. Shine the flashlight or laser pointer through the prism.
2. Observe the bending of light and the formation of a spectrum (rainbow).

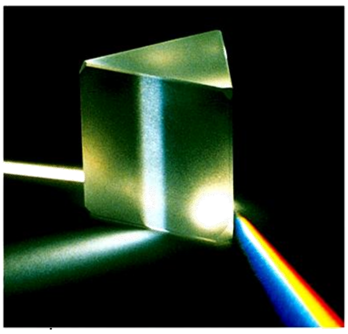
Observations:

- The light bends as it enters and exits the prism.
- White light splits into its component colours, forming a rainbow.

Science Explanation:

Refraction occurs because light travels at different speeds in different materials. White light is composed of many colours, each with a distinct wavelength. **The prism separates these colours, creating a spectrum.** This is how rainbows form in nature, when sunlight passes through water droplets in the air. **Shorter wavelengths** (blue) **are refracted at greater angles than longer wavelengths** (red).





C. DIFFRACTION and INTERFERENCE

A diffraction grating has many closely spaced lines. When light passes through a diffraction grating, **it spreads out and interferes**, creating a pattern of bright and dark spots. This demonstrates **the wave nature of light**. The positions of the bright spots depend on the **wavelength of the light** and **the grating spacing**.

Materials: Diffraction grating, laser pointer

Activity:

- Shine the laser pointer through the diffraction grating onto a wall.
- Observe the pattern of bright spots (diffraction maxima).

Setup & Procedure:

1. Shine the laser pointer through the diffraction grating onto a wall or screen.
2. Observe the pattern of bright spots (diffraction maxima).

Observations:

- You'll see a central bright spot and several others on either side, forming a pattern.

Grating Equation

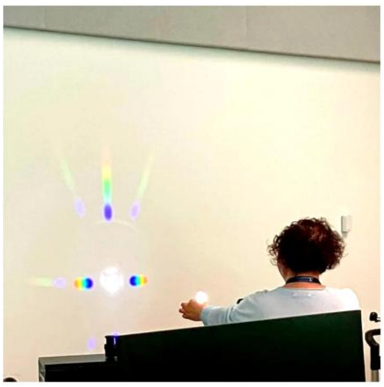
The grating equation gives the positions of the bright spots (maxima):

$$d\sin\,\theta = n\lambda$$

where:

- d= distance between adjacent slits (grating spacing)
- θ= angle at which a bright spot appears
- n= order of the maximum (0, 1, 2, ...)
- λ= wavelength of the light

The interference pattern arises because light waves from different slits travel different distances to reach the screen. **When the path difference matches certain conditions**, the waves combine constructively or destructively, producing the observed pattern of bright and dark spots.



D. POLARIZATION

Polarization of Light

Materials: Polarizer filters, flashlight, or laser pointer

Activity:

- Shine the flashlight or laser pointer through one polarizer.
- Rotate a second polarizer in front of the first and observe the change in light intensity.

Setup & Procedure:

1. Shine the flashlight through one polarizer filter.
2. Place the second polarizer in the path of the light.
3. Slowly rotate the second polarizer and observe the brightness of the transmitted light.

Observations:

- When the polarizers are aligned, light passes through easily.
- As you rotate the second polarizer, the light dims and can be blocked completely.

Science Explanation:

Light waves vibrate in many directions. A polarizer only allows light vibrating in one direction to pass. When two polarizers are aligned, they transmit light of the same orientation. Rotating the second polarizer blocks more light, demonstrating how polarizers filter light based on its orientation. This principle is used in sunglasses and photography to reduce glare.