SESSION 5: INVESTIGATING LIGHT

Key Concepts
In this session we:

- Explain what light is, where light comes from and why it is important
- Identify what happens when light strikes the surface of different objects
- Explain the processes of reflection, refraction, total internal reflection and diffraction

X-planation

What is light?
Light is an example of electromagnetic radiation that we can detect with our eyes. Electromagnetic radiation is a form of energy that is transport by electromagnetic waves. These wave all travel at the speed of light, $c$, which is $3 \times 10^8$ m.s$^{-1}$ in a vacuum. As far as we know nothing travels faster than the speed of light.

All electromagnetic waves are produced when a charge particle is accelerated. There are two components formed:
- A changing electric field and
- A changing magnetic field

These components lie at $90^0$ to each other and are self propagating. The changing electric field produces a changing magnetic field and a changing magnetic field produces a changing electric field.

Light has all the properties of waves:
- Light travels in straight lines
- Light is reflected
- Light is refracted
- Light is diffracted
Light undergoes interference

Where does light come from?
Light is obtained from a luminous source, e.g. the sun, a light bulb, or candle

Light also enters our eyes when it is reflected off a surface. This surface becomes an illuminated source, e.g. the moon, a mirror, a movie screen or any object you see.

Why is light important?
Light enables us to make sense of the world around us. Light is a form of energy that plants use to make food in the process of photosynthesis. No life could exist on Earth without this process.

What happens when light strikes an object?
All objects can be classed as:

- **Transparent**
  Objects that allow light to pass through them with little or no resistance. You can see clearly through a transparent material.
  Examples: water, glass, perspex.

- **Translucent**
  Objects that allow light to pass through them but diffuses or scatters the light. You cannot see clearly through a translucent material.
  Example: Some plastics, coloured glass, cotton cloth.

- **Opaque**
  Objects that absorb, scatter or reflect light and do not allow any light to pass through. You cannot see through opaque objects. Examples: Wood, metal

When light hits an object, one of three things can happen:
1. Absorbed
2. Reflected
3. Refracted

**Reflection of light**
When light shines on a shiny surface such a mirror, the light is reflected back, away from the surface. This reflection is occurs in a regular, specific way.

- The **normal** is an imaginary line perpendicular (at 90°) to the surface. All angles are measured from the normal.
- The **incident ray** is the original light ray
- The **reflected ray** is the ray that is reflected off the surface.
- **\( \theta_i \)** is the angle of incidence. It is the angle between the normal the incident light ray

- \( \theta \) is the **angle of reflection**. It is the angle between the normal the reflected light ray.

**Laws ofReflection**
1. The incident ray, the reflected ray and the normal are all in the same plane.
2. The angle of incidence is equal to the angle of reflection.

**Refraction of light**
Refraction is the change of speed of light when it moves from one medium into another. For example when light moves from air into glass it slows down but when it moves from glass to air it speeds up. We can measure the speed of light in different materials and compare this speed to the speed of light in a vacuum, \( c \). Each material has its own refractive index, \( n \).

**Refractive index:** The refractive index \( n \) of a material is the ratio of the speed \( c \) of light in a vacuum to the speed \( v \) of light in the material.

\[
n = \frac{\text{speed of light in a vacuum} (c)}{\text{speed of light in the material} (v)}
\]

**Table of Substances and their Refractive Indices**

<table>
<thead>
<tr>
<th>Substance</th>
<th>Refractive index</th>
<th>Substance</th>
<th>Refractive index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1,0</td>
<td>Glass</td>
<td>1,52</td>
</tr>
<tr>
<td>Ice</td>
<td>1,31</td>
<td>Amber</td>
<td>1,55</td>
</tr>
<tr>
<td>Water (20(^\circ))</td>
<td>1,33</td>
<td>Ruby</td>
<td>1,76</td>
</tr>
<tr>
<td>Ethanol</td>
<td>1,36</td>
<td>Sapphire</td>
<td>1,76</td>
</tr>
<tr>
<td>Plastic</td>
<td>1,46</td>
<td>Cubic zirconium</td>
<td>2,18</td>
</tr>
<tr>
<td>Perspex</td>
<td>1,50</td>
<td>Diamond</td>
<td>2,42</td>
</tr>
</tbody>
</table>

A substance with high refractive index greater than 1,75 has a high optical density.
A substance with low refractive index close to 1,0 has a low optical density.

**Refraction of light through a rectangular glass block**

When light moves from air into glass it will slow down and so is refracted. When the light moves from inside the glass block back into air it will speed up and so will be refracted again.

There are two different examples shown in the diagram:

- When a beam of light strikes the surface along the normal (angle of incidence \( \theta_i = 0^\circ \)), the light changes speed but continues straight through the glass.
- When a beam of light strikes the surface at an angle of incidence between 0° and 90° (0° < θᵢ < 90°) you can see the effect of the change in speed of light. The beam of light changes direction. When it is slowing down it moves towards the normal (angle of refraction θᵣ is less than the angle of incidence θᵢ) but when the light speeds up, the beam moves away from the normal (angle of refraction θᵣ is greater than the angle of incidence θᵢ). Notice that since the sides of the rectangular block are parallel to each other the beam of light entering the block (incident ray) and the beam leaving the block (emergent ray) are parallel to each other too.

![Diagram of light refraction and total internal reflection](image)

The relationship between the angle of incidence θᵢ, the angle of refraction θᵣ, and the refractive index is described by Snell's Law.

**Snell's Law of Refraction:**
When light travels from a material with refractive index n₁ into a material with refractive index n₂, the refracted ray, the incident ray and the normal to the interface between the materials all lie in the same plane.

The angle of refraction, r, is related to the angle of incidence, i, by:

\[ n₁ \sin θᵢ = n₂ \sin θᵣ \]

**Total Internal Reflection**
When light moves from a medium of higher optical density towards a medium with lower optical density and it strikes the surface at a large angle of incidence, the beam is reflected back into the medium with higher optical density. This phenomenon is known as total internal refraction.

The conditions for total internal refraction to take place:

1. Light ray must move from greater optical density to a medium with lower optical density
2. Angle of incidence must be greater than the critical angle

The **critical angle** of a substance is the angle of incidence when the beam emerging from an optically more dense medium has an angle of refraction equal to 90°, i.e. along the surface of the medium.

**Diffraction** is the bending of waves behind a barrier or after passing through a small slit or gap in a barrier.

**Diffraction of light**

When the light is diffracted through a single slit barrier a unique pattern can be observed on a screen.

There is a bright central band (Y) with alternating dark bands (X and Z) on each side of the central band. The bright bands next to X and Z are less intense than the central bright band (Y). The intensity of the bright band decreases the further they are from the central band. The bright bands are a result of constructive interference and the dark bands are a result of destructive interference.

The amount of diffraction is dependent on the width of the slit.
- The narrower the slit the greater the diffraction and the wider the central band.
- Maximum diffraction happens when the slit width is equal to the wavelength of the wave passing through the slit.
- When the slit is wider, then the diffraction is less and the central band is narrower.
**X-ample Questions**

**Question 1**
Draw a diagram to show the path of light passing through a triangular prism.

![Diagram of light passing through a triangular prism](image)

**Question 2**
Draw a diagram to show the path of light passing through a triangular prism. The critical angle for this prism is 42\(^\circ\).

![Diagram of light passing through a triangular prism](image)

**X-ercises**

**Question 1**
Complete the table below to describe what happens when light moves across the boundary between air and water. The critical angle of water at 20\(^\circ\)C is 48,75\(^\circ\).

<table>
<thead>
<tr>
<th>Angle of incidence</th>
<th>Substance 1</th>
<th>Substance 2</th>
<th>Change in speed</th>
<th>Angle of refraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0(^\circ)</td>
<td>Air</td>
<td>Water</td>
<td>(A)</td>
<td>(B)</td>
</tr>
<tr>
<td>(C)</td>
<td>Water</td>
<td>Air</td>
<td>(D)</td>
<td>90(^\circ)</td>
</tr>
<tr>
<td>48,75(^\circ)</td>
<td>(E)</td>
<td>(F)</td>
<td>Slows down</td>
<td>--------------------</td>
</tr>
<tr>
<td>60(^\circ)</td>
<td>Water</td>
<td>Air</td>
<td>(G)</td>
<td>--------------------</td>
</tr>
<tr>
<td>30(^\circ)</td>
<td>(H)</td>
<td>(I)</td>
<td>(J)</td>
<td>41,68(^\circ)</td>
</tr>
</tbody>
</table>
Answers to X-ercises

1  A  Slows down
   B  0°
   C  48,75° (Critical angle)
   D  Speeds up
   E  Air
   F  Water
   G  No change
   H  Water
   I  Air
   J  Speeds up