2. Light & Electromagnetic Spectrum

2. Light/Electromagnetic Spectrum – (10 lessons)
   – EM spectrum – (2 lessons)
   – Essay (2 lessons)
   – Light Basics – (1 lesson)
   – Reflection in Plane mirrors – (2 lessons)
   – Refraction – (3 lessons)
     • Snell’s Law
     • Dispersion
     • Total Internal Reflection/Critical Angle
   – Lenses – (2 lessons)
     • Basics
     • Thin Lens equation/Lens maker formula
     • Magnification
     • Application
The Electromagnetic Spectrum

Light is an electromagnetic wave. It turns out our eyes can only see certain wavelengths. Most electromagnetic radiation cannot be detected by our eyes.

However, you are already familiar with most parts of the electromagnetic spectrum.
The Electromagnetic Spectrum

The higher the frequency, the higher the energy.
Electromagnetic Spectrum

The following slides explain which part of the EM spectrum has which purpose.
EM Radiation: Gamma

Uses:
Kills harmful bacteria in food, sterilising surgical equipment, killing cancer cells (radiotherapy)

Dangers:
High doses can kill cells.
Lower doses can cause cells to become cancerous.
EM Radiation: X rays

Uses:
Shadow pictures of luggage and inside the human body.

Dangers:
(High doses can kill cells.)
Lower doses can cause cells to become cancerous.

How do hospital workers limit their exposure to Gamma and X rays?

Hospital workers limit exposure to Gamma and X rays by standing behind lead shields or by leaving the room when the radiations are being used.
X rays can penetrate soft tissue but not bone. X rays are absorbed more by some materials than others. Photographic film is used to detect X rays.
EM Radiation: Ultraviolet

Uses:
Sun beds, fluorescent lamps and security marking, checking bank notes for fraud.

Dangers:
High doses can kill cells (surface). Lower doses can cause cells to become cancerous (skin cancer).

Which type of radiation is the most dangerous?

The higher the frequency of the radiation, the more dangerous it is. So gamma is more dangerous than X rays or ultraviolet.
Effects of EM radiation on living cells

Ultraviolet radiation can pass through skin to deeper tissues and cause sunburn and potentially skin cancer.

What effect do you think the colour of the skin has on the amount of radiation that passes through it?

The darker the skin, the more ultraviolet radiation is absorbed, the less can reach into deeper soft tissues.
EM Radiation:

Light

Uses:
Vision, endoscopes, photography

Dangers:
Blindness
EM Radiation: **Infrared**

**Uses:**
Remote controls (TV/VCR), radiant heaters, grills, optical fibre communication, thermograms.

**Dangers:**
Skin burns
Night vision

All objects above absolute zero emit infrared radiation. The hotter an object is, the more heat radiation it emits. Some animals and cameras can detect infrared radiation and are able to build up a heat picture.

Which are the hottest/coolest parts of the image shown?

- Light is hot
- Dark is cold
EM Radiation: **Microwaves**

**Uses:**
- Satellite communication,
- mobile phone networks,
- cooking, RADAR.

**Dangers:**
- Internal tissue heating.
Microwaves

How do microwaves cook foods?

Microwaves can be used in cooking because many foods contain water molecules. Microwaves of the right wavelength are able to make the water molecules resonate. This causes the food to get hotter.
EM Radiation:
Radio waves

Uses:
Communication and astronomy.

Dangers:
none known
Radio waves

How do radio signals from the UK reach around the globe?

The longer wavelength radio waves from a transmitter reflect off the Earth’s outer atmosphere (ionosphere).
How can houses in the shadows of hills receive a radio signal?

All electromagnetic radiation travels in straight lines, does it not?

Radio waves diffract around the hill to the house.

Remember diffraction?
Getting hotter

If electromagnetic radiation is incident upon a material what effects could it have?

An alternating current could be induced in the material, with the same frequency as the incident radiation.

The temperature of the material could increase.
1) Match up the following parts of the electromagnetic spectrum with their uses:

- Gamma rays: Allow us to see
- Radio waves: Remote Controls
- Ultra Violet: ‘See’ broken bones
- Visible: Carry TV signals
- Microwaves: RADAR
- X rays: Sterilise equipment
- Infra Red: Causes sun-tans
2) Which radiations are missing from below?

<table>
<thead>
<tr>
<th>Gamma</th>
<th>A</th>
<th>Ultraviolet</th>
<th>Light</th>
<th>Infrared</th>
<th>B</th>
<th>Radio waves</th>
</tr>
</thead>
</table>

A. **X rays**

B. **Microwaves**
Dispersion Summary

Red/violet
Refracted more/less by glass
Longer/shorter wavelength

Red/violet
Refracted more/less by glass
Longer/shorter wavelength
The Electromagnetic Spectrum

Light, a type of radiation, is part of the electromagnetic spectrum.
The electromagnetic spectrum is made up of different types of radiation.
The different types of radiation have different properties and behaviour.
All electromagnetic waves can travel through space.
All electromagnetic waves travel at the same speed in a vacuum [300,000,000 m/s].

TRUE/FALSE
TRUE/FALSE
TRUE/FALSE
TRUE/FALSE
TRUE/FALSE
We can see the relationship between colour, wavelength and amplitude using this animation.
Electromagnetic Spectrum

Although all e-m waves travel at the same speed, their wavelength \([\lambda]\) and frequency \([f]\) can be different.

Waves that cook food.

Waves that cause sun-tans.

The properties, dangers and uses of e-m waves depends on the wavelength \([\lambda]\).
Electromagnetic Spectrum

Wavelength ($\lambda$) increases

Gamma | X-rays | Ultra-Violet | Light | Red | Infra-Red | Micro | Radio

High frequency
Short wavelength
High energy
Most penetrating

Low frequency
Long wavelength
Low energy
Least penetrating
<table>
<thead>
<tr>
<th>Radiation</th>
<th>Uses</th>
<th>Dangers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-rays</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultraviolet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infra red</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microwaves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radio waves</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
E = hf
Reflection, Refraction, Dispersion and Total Internal Reflection
Light

• Travels at a speed of $3.00 \times 10^8$ ms$^{-1}$ in vacuum and almost just as fast in air.
• There is nothing in the universe that travels at a faster speed than any EM radiation.
• Light transfers energy (photovoltaic cells).
• Light can travel through empty space (vacuum). It does not need a medium like sound.
• Light travels in straight lines.
• Waves/particles
Reflection: basics

• Set up an experiment to find out the relationship between the angle of incidence and the angle of reflection.
Reflection on smooth and rough surfaces

• Give two examples each for smooth and rough surfaces in the room.
Reflection and image formation
Refraction: examples
Refraction through glass & water

Light Refraction Through Glass and Water

Figure 1
Refraction

If the light travels more slowly ($v$ decreases) and $f = \text{constant}$, then $\lambda$ must decrease:

$v = \lambda f$
Refraction: Snell’s law

\[ \frac{v_2}{v_1} = \frac{n_1}{n_2} = \frac{\sin \theta_2}{\sin \theta_1} \]

\( n \) is called the **refractive index**. It does not have any unit. The higher the refractive index, the greater the degree of refraction.
# Refractive indices

<table>
<thead>
<tr>
<th>Material</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>1</td>
</tr>
<tr>
<td>Air at STP</td>
<td>1.00029</td>
</tr>
<tr>
<td>Ice</td>
<td>1.31</td>
</tr>
<tr>
<td>Water at 20 C</td>
<td>1.33</td>
</tr>
<tr>
<td>Acetone</td>
<td>1.36</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>1.36</td>
</tr>
<tr>
<td>Sugar solution (30%)</td>
<td>1.38</td>
</tr>
<tr>
<td>Glycerine</td>
<td>1.473</td>
</tr>
<tr>
<td>Sugar solution (80%)</td>
<td>1.49</td>
</tr>
<tr>
<td>Typical crown glass</td>
<td>1.52</td>
</tr>
<tr>
<td>Crown glasses</td>
<td>1.52-1.62</td>
</tr>
<tr>
<td>Flint glasses</td>
<td>1.57-1.75</td>
</tr>
<tr>
<td>Heavy flint glass</td>
<td>1.65</td>
</tr>
<tr>
<td>Diamond</td>
<td>2.417</td>
</tr>
</tbody>
</table>
Explaining dispersion

The white light ray is split into a spectrum of colours. This is known as DISPERSION.

The different colours of light have different wavelengths. Different wavelengths are refracted different amounts.

Richard Of York Gave Battle In Vain

Which colour is refracted the most?

Red light is refracted least.

Violet light is refracted the most.
Total Internal Reflection

At what angle of incidence did the ray change from refraction to reflection?

It depends upon the material you used.
Total Internal Reflection

This angle is called the \textit{critical angle} [$\theta_c$]

\begin{align*}
\theta_i &< \theta_c \\
\theta_i &= \theta_c \\
\theta_i &> \theta_c
\end{align*}

Refraction \hspace{2cm} Critical case \hspace{2cm} Total Internal Reflection [TIR]

Different materials have different critical angles. Diamond has the lowest at 24° which is why it reflects so much light.
How does refractive index affect the critical angle?

Research the missing values below and then make a conclusion…

<table>
<thead>
<tr>
<th>Material</th>
<th>Refractive index</th>
<th>Critical angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>1.5</td>
<td>42°</td>
</tr>
<tr>
<td>Water</td>
<td>1.33</td>
<td>49°</td>
</tr>
<tr>
<td>Diamond</td>
<td>2.4</td>
<td>24°</td>
</tr>
</tbody>
</table>

The greater the refractive index the smaller the critical angle.
Total Internal Reflection

Optical fibres use total internal reflection to transmit light. Light enters the fibre, is refracted, and travels down the fibre through repeated total internal reflections.

What are the applications of total internal reflection?

You could be asked to draw the path of the beam in an exam.

...NOTE how it is refracted as it enters the fibre...

...it travels down the fibre through repeated total internal reflections.
Further Uses of TIR

- Fibre optics (communication)
- Binoculars
TIR and the rainbow
Read while lying flat; prism turns page 90°.
Lenses

Waves
Keywords: converge, diverge, focal length, principal focus, principal axis

Note: the light will only focus at the principal focus if the incoming rays of light are parallel.
Concave lens: incoming rays of light not in parallel
Concave lens: incoming rays of light not parallel
Power of a lens

• Power of a lens = 1/focal length
• P = 1/f
• Unit of P: dioptre (dpt)
• The shorter the focal length is the higher the power of the lens.
• What is the power of your glasses? Calculate the focal length!
Linear Magnification

The linear magnification is equal to the ratio of image height to object height.

\[ M = \frac{h_i}{h_o} \]

Mathematically this is equal to the result of \( q/p \) (often referred to as \( v \) and \( u \) respectively)
u, v and f
Image formation: object further than 2F

The further the object is from the lens the closer the image to F.
Object between 2F and F

Image at a distance greater than 2F!

Nature of image:
real, bigger, further, upside down
Object between F and center of lens

If the object is closer than F, the image will be virtual (magnifying glass).
A virtual image is always obtained by extending the rays of light to where our eyes expect them to cross.

Note: the focal length of a concave lens is negative (convention)!
Real image: the rays come from the image (to the eye).

Virtual image: the rays only appear to come from the image.
Thin lens formula

• $1/f = 1/u + 1/v$
• Only applies to thin lenses!
• $v$: positive for real images, negative for virtual images
The Human Eye

- iris
- cornea
- pupil (light enters eye)
- lens
- ciliary muscles
- retina (image focused here)