OCR A Level Physics

Your notes

EM Waves

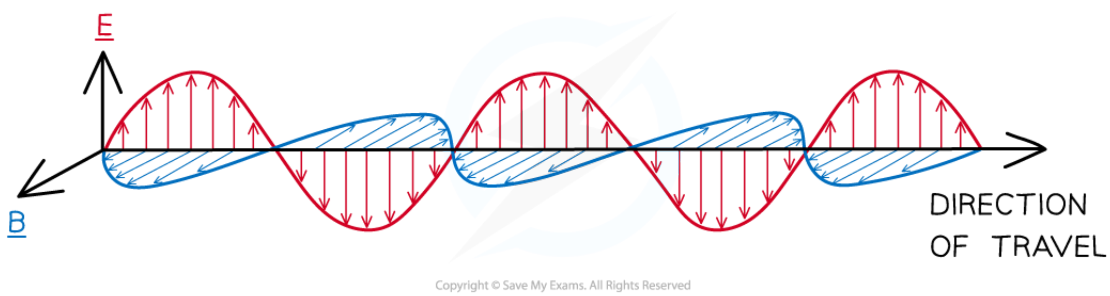
Contents

The Electromagnetic Spectrum

Your notes

Properties of Electromagnetic Waves

- Visible light is just one part of a much bigger spectrum: **The Electromagnetic Spectrum**
- All electromagnetic waves have the following properties in common:
  - They are all **transverse** waves
  - They can all travel in a **vacuum**
  - They all travel at the **same speed** in a vacuum (free space) — the speed of light
- The speed of light in air is approximately the same as in a vacuum

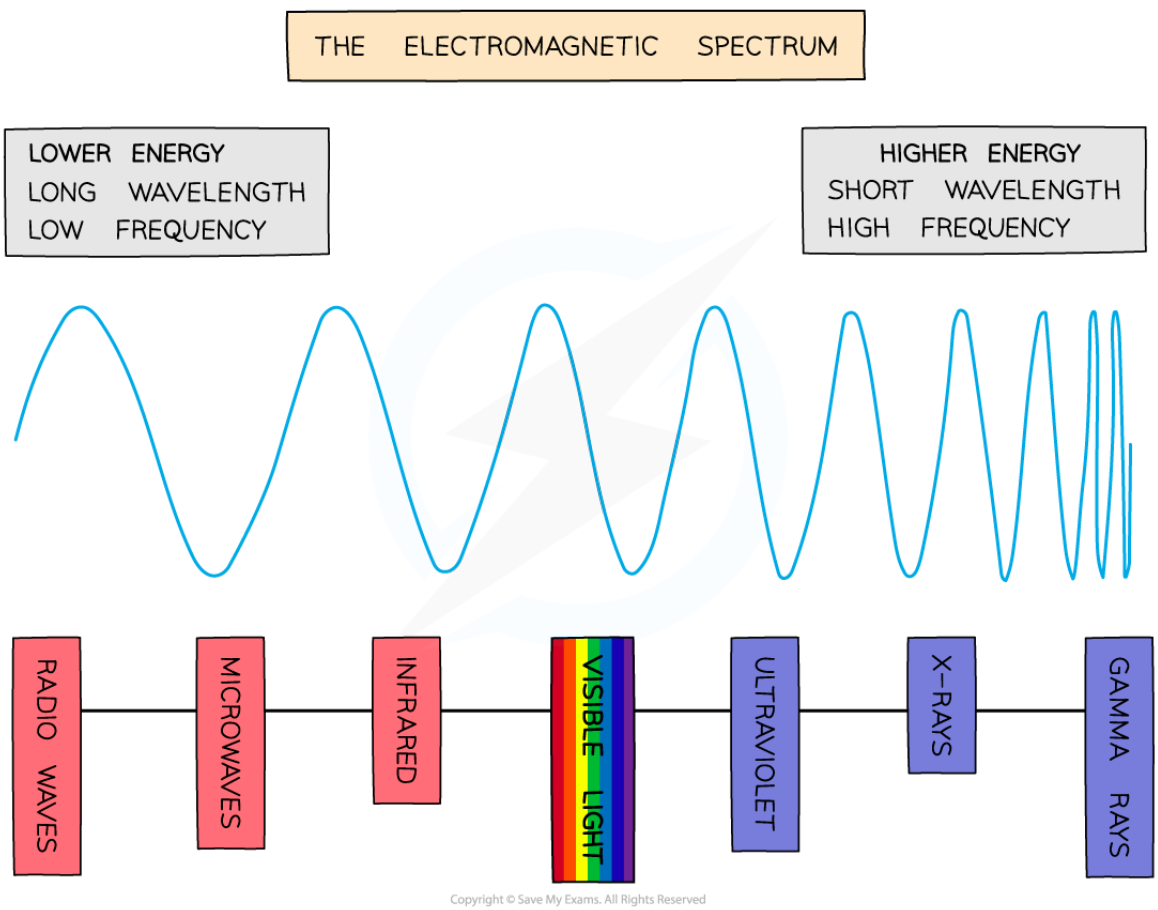


Oscillating electric and magnetic fields in an electromagnetic wave

- These transverse waves consist of electric and magnetic fields oscillating at right angles to each other and to the direction in which the wave is travelling (in 3D space)
- Since they are transverse, all waves in this spectrum can:
  - Reflect
  - Refract
  - Diffract
  - Be polarised
  - Produce interference patterns

The Electromagnetic Spectrum

- The electromagnetic spectrum (EM) is arranged in a specific order based on the wavelengths or frequencies
- This order is shown in the diagram below from longest wavelength (lowest frequency) to shortest wavelength (highest frequency)



Energy, wavelength and frequency for each part of the electromagnetic spectrum

- The higher the **frequency**, the higher the **energy** of the radiation
- Radiation with higher energy is highly ionising and is harmful to cells and tissues causing cancer (e.g. UV, X-rays, Gamma rays)

Uses of EM Waves

- Electromagnetic waves have a large number of uses

Your notes

- The main uses are summarised in the table below:

WAVE	USE
RADIO	• COMMUNICATION (RADIO AND TV)
MICROWAVE	• HEATING FOOD • COMMUNICATION (WIFI, MOBILE PHONES, SATELLITES)
INFRARED	• REMOTE CONTROLS • FIBRE OPTIC COMMUNICATION • THERMAL IMAGING (MEDICINE AND INDUSTRY) • NIGHT VISION • HEATING OR COOKING THINGS • MOTION SENSORS (FOR SECURITY ALARMS)
VISIBLE LIGHT	• SEEING AND TAKING PHOTOGRAPHS/VIDEOS
ULTRAVIOLET	• SECURITY MARKING (FLUORESCENCE) • FLUORESCENT BULBS • GETTING A SUNTAN.
X-RAYS	• X-RAY IMAGES (MEDICINE, AIRPORT SECURITY AND INDUSTRY)
GAMMA RAYS	• STERILISING MEDICAL INSTRUMENTS TREATING CANCER

Wavelengths in the Electromagnetic Spectrum

- The approximate wavelengths in a vacuum of each radiation are listed in the table below:

Table of EM spectrum wavelengths and frequencies

Your notes

Radiation	Approximate wavelength range / m	Approximate frequency range / Hz
Radio	> 0.1	$< 3 \times 10^{9}$
Microwaves	$0.1 - 1 \times 10^{-3}$	$3 \times 10^{9} - 3 \times 10^{11}$
Infra-red	$1 \times 10^{-3} - 7 \times 10^{-7}$	$3 \times 10^{11} - 4.3 \times 10^{14}$
Visible	$4 \times 10^{-7} - 7 \times 10^{-7}$	$7.5 \times 10^{14} - 4.3 \times 10^{14}$
Ultra-violet	$4 \times 10^{-7} - 1 \times 10^{-8}$	$7.5 \times 10^{14} - 3 \times 10^{16}$
X-rays	$1 \times 10^{-8} - 4 \times 10^{-13}$	$3 \times 10^{16} - 7.5 \times 10^{20}$
Gamma rays	$1 \times 10^{-10} - 1 \times 10^{-16}$	$3 \times 10^{18} - 3 \times 10^{24}$

- To alternatively find the range of frequencies, convert the wavelengths using the wave equation: $c = f\lambda$ where c is the speed of light: 3.0×10^{8} m s^{-1}

Worked Example

A is a source emitting microwaves and **B** is a source emitting X-rays. The table suggests the frequencies for **A** and **B**.

Your notes

	Frequency emitted by A/Hz	Frequency emitted by B/Hz
A	$3 \times 10^9 - 3 \times 10^{11}$	$> 10^{19}$
B	$1 \times 10^{12} - 1 \times 10^{13}$	$3 \times 10^{16} - 7.5 \times 10^{20}$
C	$3 \times 10^9 - 3 \times 10^{11}$	$3 \times 10^{16} - 7.5 \times 10^{20}$
D	$4 \times 10^{14} - 8 \times 10^{14}$	$5 \times 10^{13} - 7 \times 10^{15}$

Which row is correct?

ANSWER: C

STEP 1

THE WAVE EQUATION

$c = f\lambda$

STEP 2

REARRANGE FOR FREQUENCY

$f = \frac{c}{\lambda}$

Your notes

STEP 3

THE RANGE OF WAVELENGTH FOR MICROWAVES IS $0.1 - 1 \times 10^{-3}$ m

USE WAVE EQUATION TO FIND EQUIVALENT FREQUENCIES FOR MICROWAVES

$f = \frac{3 \times 10^8}{0.1} = 3.0 \times 10^9$ $f = \frac{3 \times 10^8}{1.0 \times 10^{-3}} = 3.0 \times 10^{11}$

$f = 3.0 \times 10^9 - 3.0 \times 10^{11}$ Hz

STEP 4

THE RANGE OF WAVELENGTH FOR X-RAYS IS $1 \times 10^{-8} - 4 \times 10^{-13}$ m

USE WAVE EQUATION TO FIND EQUIVALENT FREQUENCIES FOR X-RAYS

$f = \frac{3 \times 10^8}{1 \times 10^{-8}} = 3 \times 10^{16}$ Hz $f = \frac{3 \times 10^8}{4 \times 10^{-13}} = 7.5 \times 10^{20}$ Hz

$f = 3 \times 10^{16} - 7.5 \times 10^{20}$ Hz

STEP 5

ROW C MATCHES BOTH OF THESE FREQUENCY RANGES

Examiner Tips and Tricks

You will be expected to memorise the range of wavelengths for each type of radiation, however, you don't need to learn the frequency ranges by heart. Since all EM waves travel at the speed of light, you can convert between frequency and wavelength using the wave equation in an exam question.

Polarisation

Your notes

Polarisation

- Polarisation is when:

  Particle oscillations occur in only one of direction perpendicular to the direction of wave propagation

- Polarisation can only occur in transverse waves
  - This is because electromagnetic transverse waves are oscillating electric and magnetic fields in any plane **perpendicular** to the propagation direction
- When transverse waves are **polarised,** this means:
  - Vibrations are restricted to **one** direction
  - These vibrations are still **perpendicular** to the direction of propagation / energy transfer
- The difference between unpolarised and polarised waves is shown in the diagram below:

Your notes

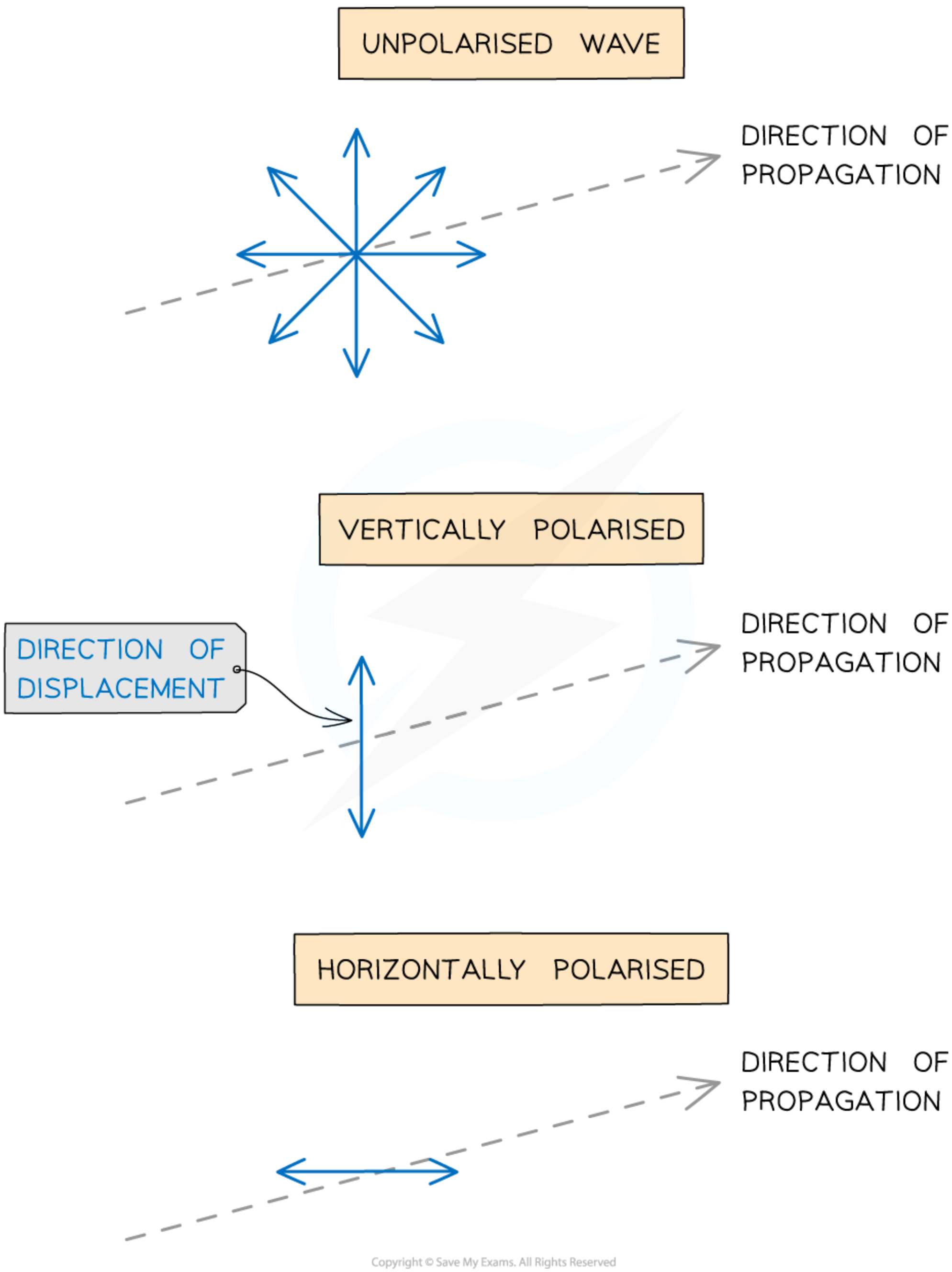


Diagram showing the displacement of unpolarised and polarised transverse waves

- Light from the sun or a lightbulb, or any that hasn't gone through a polarising filter is **unpolarised**
- Longitudinal waves (e.g. sound waves) **cannot** be polarised

Your notes

- This is because they oscillate parallel to the direction of travel
- Waves can be polarised through a **polariser** such as a **polarising filter** (light) or **metal grilles** (microwaves)
    - This only allows oscillations in a certain plane to be transmitted
    - This is called a **plane-polarised** wave

Polarising Filters

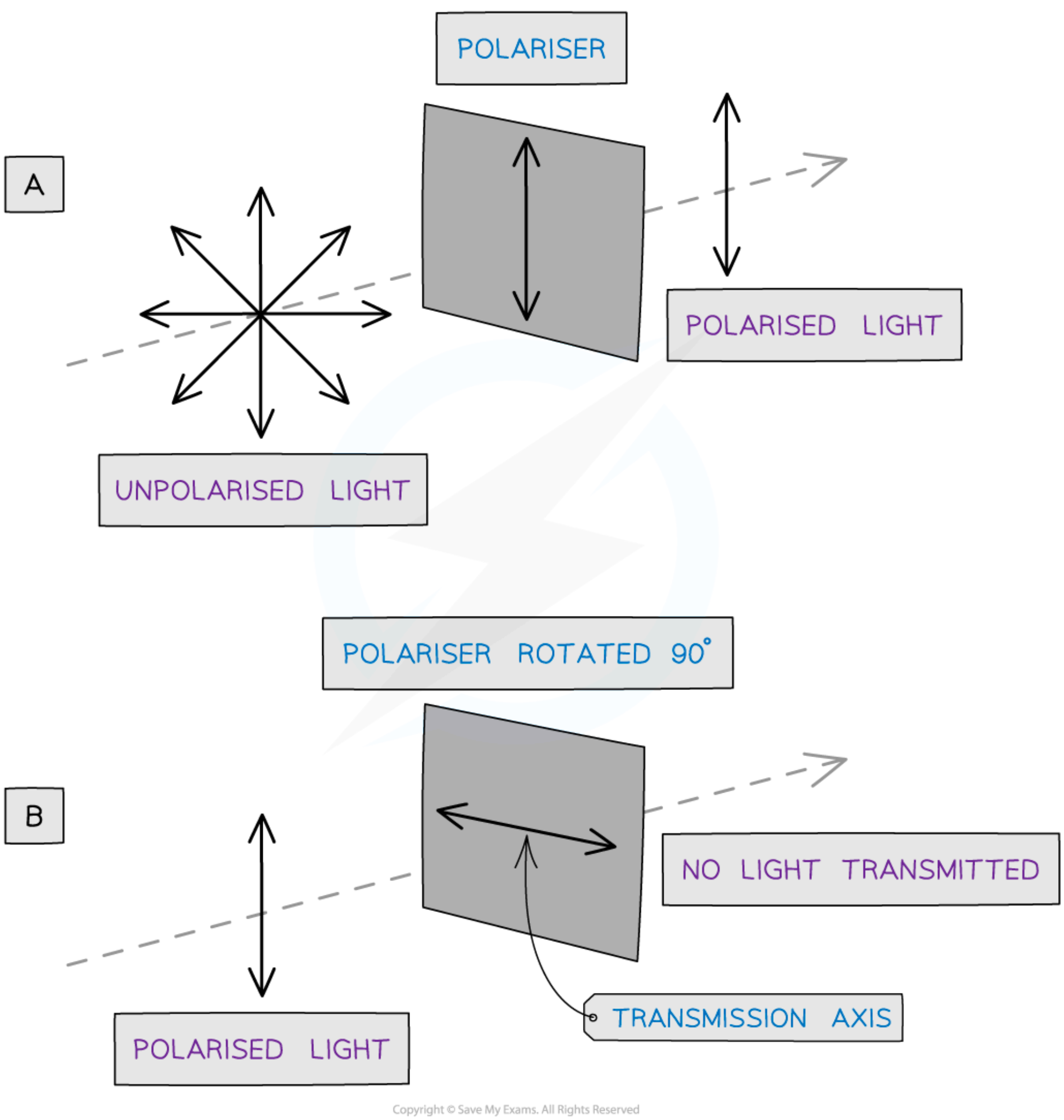


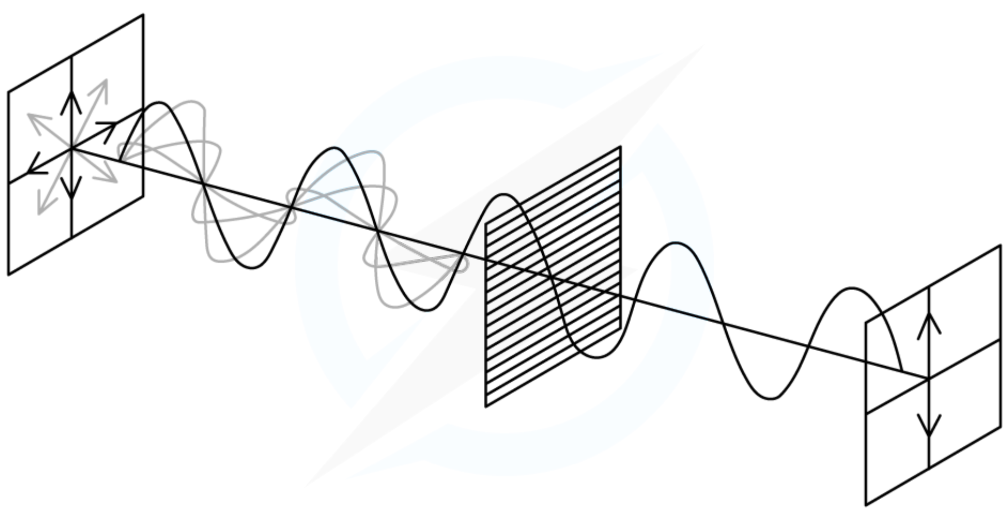
Diagram showing an unpolarised and polarised wave travelling through polarising filters

Your notes

- Diagram **A** shows:
  - Only unpolarised waves can be polarised
- Diagram **B** shows:
  - When a polarised wave passes through a filter with a transmission axis perpendicular to the wave, none of the wave will pass through
- Light can also be polarised through reflection, refraction and scattering

Metal Grilles

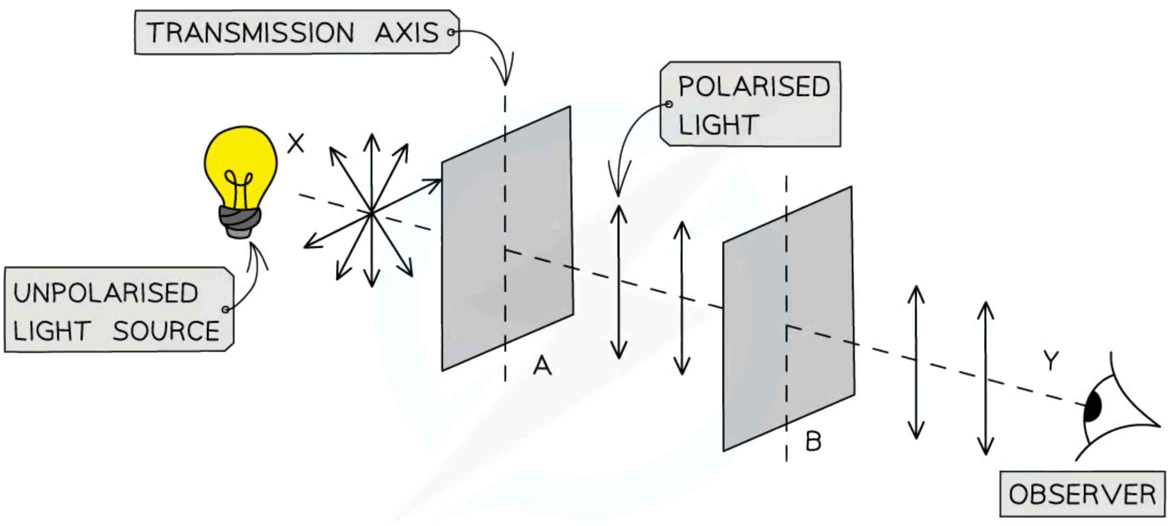
- A metal grille is similar to a polarising filter, and commonly used for polarising microwaves
  - Microwaves are electromagnetic waves with a longer wavelength than visible light
- By convention, the direction of polarisation is only the direction of the electric field propagation (rather than magnetic)
- A metal grille is different from a polarising filter
  - The free electrons moving in the metal bar can cancel out the electric field in the same direction as the grille and completely **absorb** it
  - Thus the **horizontal** electric field passes if the grilles are positioned vertically and vice versa
- This is the opposite of what happens in a polarising filter



A metal grille is used to polarise a microwave

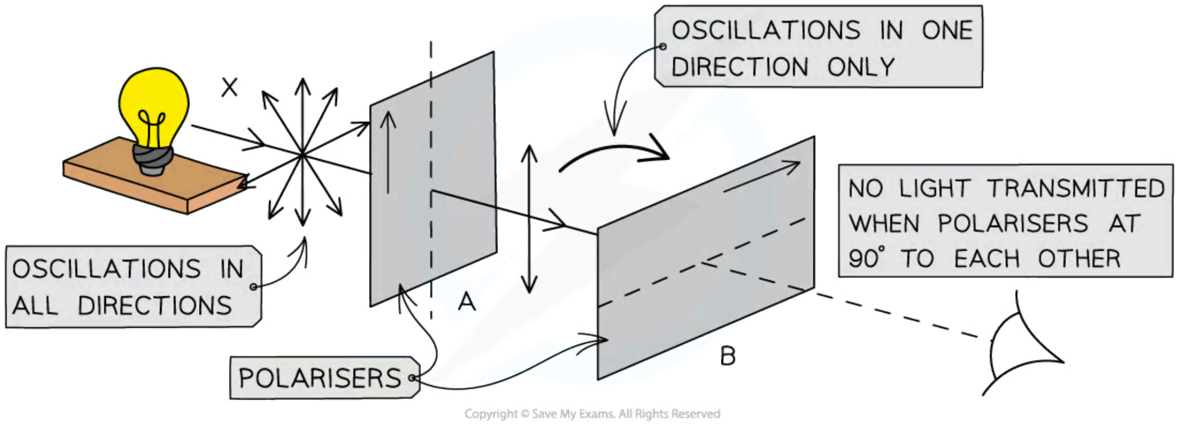
Investigating Light Intensity with Two Polarisers

- If an unpolarised light source is placed in front of two identical polarising filters, **A** and **B**, with their transmission axes **parallel**:
  - Filter **A** will polarise the light in a certain axis
  - All of the polarised light will pass through filter **B** unaffected
  - In this case, the **maximum** intensity of light is transmitted



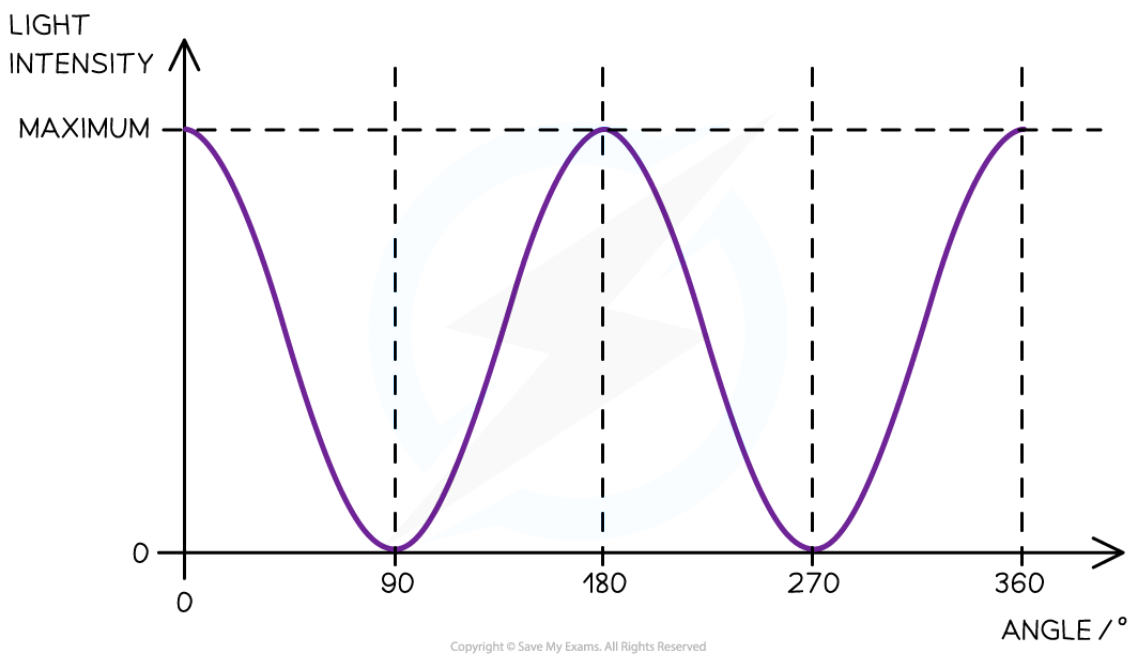
When both polarisers have the same transmission axis, the intensity of the transmitted light is at its maximum

- As the polarising filter **B** is rotated anticlockwise, the intensity of the light observed changes periodically depending on the angle **B** is rotated through
- When **A** and **B** have their transmission axes **perpendicular** to each other:
  - Filter **A** will polarise the light in a certain axis
  - This time none of the polarised light will pass through filter **B**
  - In this case, the **minimum** intensity of light is transmitted



When one of the polarisers is rotated through 90°, the intensity of the transmitted light drops to zero

- The resulting graph of the light intensity with angle, as the second polariser is rotated through 360°, looks as follows:



Graph showing how the intensity of the transmitted beam varies with the angle between the transmission axes of the two polarisers

Your notes

Worked Example

Which statement below describes a situation in which polarisation should happen?

A. Radio waves pass through a metal grid

B. Surface water waves are diffracted

C. Sound waves are reflected

D. Ultrasound waves pass through a metal grid

Answer: A

- Radio waves are transverse waves - they can be polarised by a metal grid so only the waves that fit through the grid will be transmitted, therefore, **A** is correct
- **B** cannot be correct as waves are not polarised when diffracted, but are polarised only when **reflected**, **refracted** or **scattered**
- **C** & **D** cannot be correct as **polarisation only occurs for transverse waves**, therefore, **C** & **D** can be ruled out as sound and ultrasound are both longitudinal waves

Examiner Tips and Tricks

You may be expected to describe the intensity, or even draw the graph of intensity v angle, for light with two polarisers.

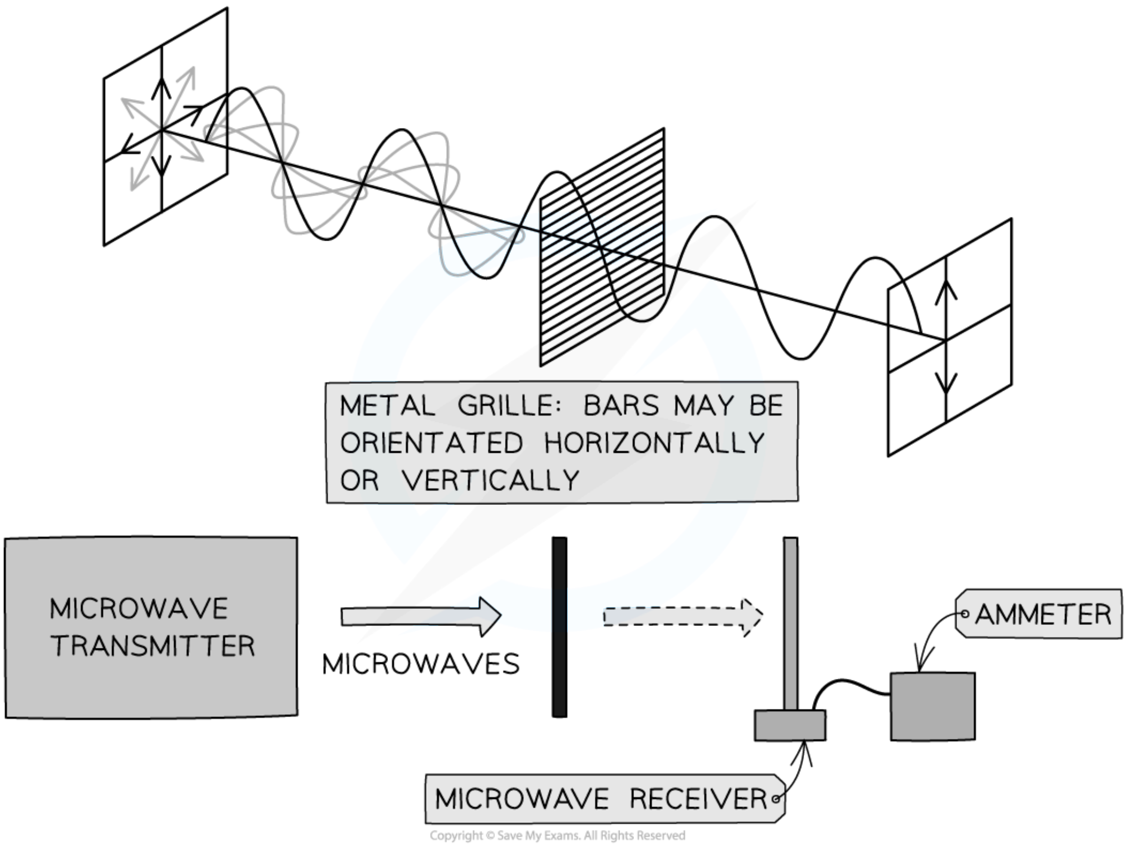
Observing Polarising Effects

Observing Polarisation of Microwaves

- A microwave transmitter can emit naturally polarised waves with a wavelength of around 3 cm
- To check whether the microwaves are polarised, place a microwave receiver in front of the transmitter and rotate about the axis through them
- The signal, which is detected using an ammeter or audio amplifier and loudspeaker will rise and fall with intensity as the receiver is rotated
- When the transmitter and the polarisation axis of the receiver are perpendicular to each other, the signal will be 0

Your notes

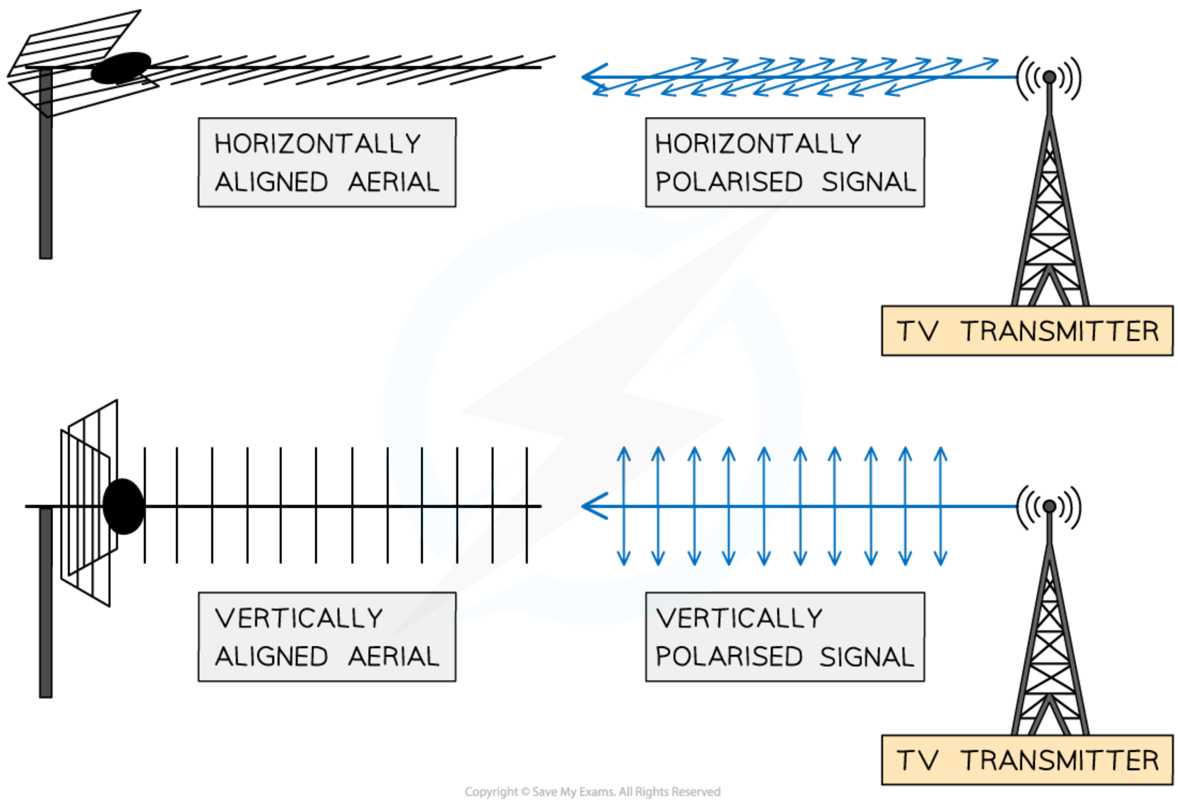
- When the receiver has a maximum signal, a metal grille can be placed between the transmitter and receiver, acting as a second polariser
- When the grille is rotated (for example, in 10° increments), the signal varies and is 0 when the metal rods are aligned with the electric field vector of the emitted microwaves
- If the microwave transmitter is producing **vertically plane-polarised** radiation:
  - If the bars of the metal grille are **horizontally orientated**, very few of the microwaves will be absorbed and the ammeter reading will be high
  - If the bars of the metal grille are **vertically orientated**, all of the microwaves will be absorbed and the ammeter reading will be zero



The polarisation of microwaves can be detected using a transmitter and receiver

- Radio and television services are broadcast either horizontally-polarised or vertically-polarised
- Therefore, the reception aerial needs to be mounted flat (horizontal), or on its side (vertical),

- The particular orientation of an aerial will depend on the transmitter it is pointing towards and the polarity of the services being broadcast

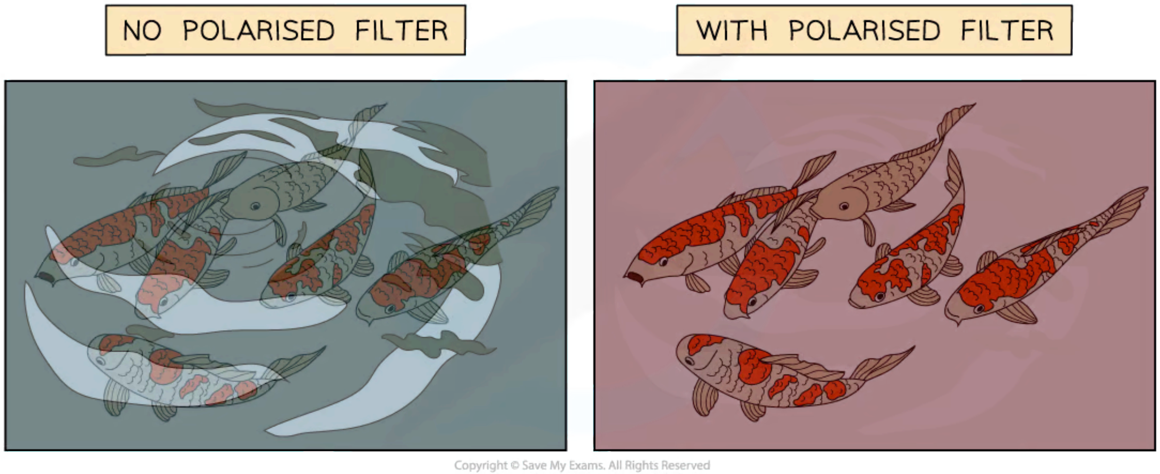


Broadcasting towers always transmit either vertically or horizontally polarised signals. This is why aerials must be positioned accordingly otherwise they won't pick up the TV signal correctly

Observing Polarisation of Light

- Polarisation of light can be observed by looking through a polarising filter at different light sources (such as the Sun, a light bulb or a laptop screen)
- This can be with two filters aligned at different angles to each other
  - As one of the filters is rotated through different angles with respect to the other, the intensity of transmitted light passing through rises and falls
- It can also be observed by looking through a single polarising filter at light reflected at a shallow angle from water, such as a pond, or from shiny surfaces in the lab
  - Rotating the polarising filter shows the reflected image become dimmer and brighter again
  - One use of this is in photography

Your notes



As well as giving a cool look to photographs, polaroid filters are extremely useful for reducing glare in photos and snapping pictures of objects underwater