EM waves: refraction and absorption

4.6.2.2 · Waves · revision notes

Different substances can absorb, transmit, refract or reflect electromagnetic waves, and what happens depends on the wavelength. You need to draw ray diagrams for refraction, explain refraction using wave fronts (Higher tier), and know the required practical on the infrared radiation emitted and absorbed by different surfaces.

Key facts

- EM waves can be absorbed, transmitted, refracted or reflected; this depends on the wavelength
- Slows down → bends towards the normal; speeds up → bends away from the normal
- Angles are measured from the normal
- Matt black: best emitter and absorber of infrared; shiny silver: worst
- Refraction = change of direction at a boundary, caused by a change in speed
- Along the normal: no change in direction
- Grade 7+ only Wave front diagrams: wave fronts are closer together in the slower medium (shorter wavelength, same frequency)

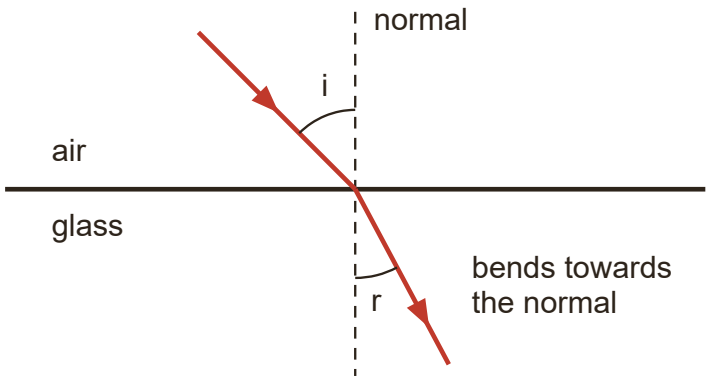
Notes

Absorb, transmit, refract or reflect

- When EM waves meet a substance they may be **absorbed**, **transmitted**, **refracted** or **reflected**. What happens depends on the substance and on the **wavelength** of the waves.
- Examples: glass transmits visible light; soft tissue in the body transmits X-rays but bone absorbs them; water in food absorbs microwaves; the ozone layer absorbs much of the Sun's ultraviolet.
- Some effects, such as refraction, happen because EM waves travel at different speeds in different substances.

Refraction and ray diagrams

- **Refraction** is the change in direction of a wave when it crosses a boundary between two media at an angle, because its speed changes.
- Light slows down when it passes from air into glass, water or Perspex, and bends **towards the normal**. When it speeds up (e.g. from glass into air) it bends **away from the normal**.

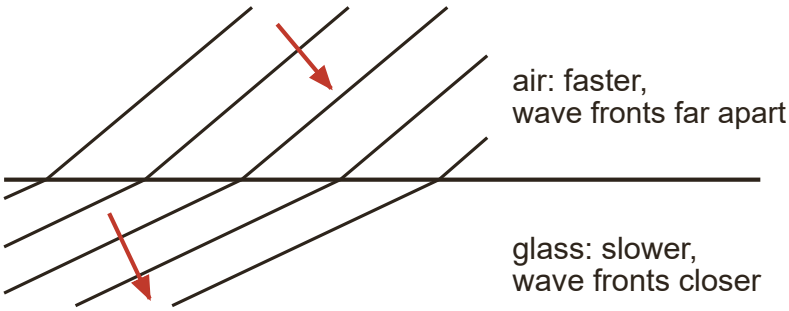


Light slows down in glass and bends towards the normal (r is smaller than i).

- A ray that meets the boundary along the normal does not change direction, but its speed still changes.
- In a ray diagram, draw the normal (dashed) where the ray meets the boundary, and measure the angles of incidence and refraction from the normal.
- For a rectangular glass block, the ray that comes out is parallel to the ray that went in, but shifted sideways.

Wave front diagrams Grade 7+ only

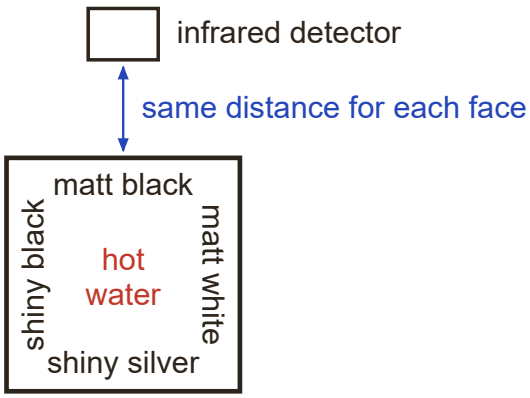
- Wave fronts are lines joining matching points on a wave, such as the crests. The gap between neighbouring wave fronts is one wavelength.
- When wave fronts meet a boundary at an angle, one end reaches the new medium first. If the wave is slower there, that end slows down while the rest of the wave front is still moving faster, so the wave front changes direction.
- In the slower medium the wave fronts are closer together (a shorter wavelength), because the frequency does not change.



The end of each wave front that reaches the glass first slows down, so the wave turns towards the normal.

Required practical: infrared and different surfaces

- Fill a Leslie cube (a metal cube whose faces are, for example, matt black, shiny black, matt white and shiny silver) with hot water, so every face is at the same temperature.
- Hold an infrared detector the same distance from each face in turn and record the readings.



Leslie cube: all faces are at the same temperature; only the surface changes.

- Result: the matt black face emits the most infrared and the shiny silver face the least.
- Absorption version: put equal volumes of cold water at the same starting temperature in two identical flasks, one matt black and one shiny silver, each the same distance from an infrared heater.
- Switch on the heater and record both temperatures every minute for 10 minutes. The matt black flask warms fastest.
- Emission version: put equal volumes of the same hot water in both flasks and record each temperature as they cool. The matt black flask cools fastest.
- Matt black surfaces are also the best absorbers of infrared, and shiny surfaces the worst, because shiny surfaces reflect most of it.

How to answer each type of question

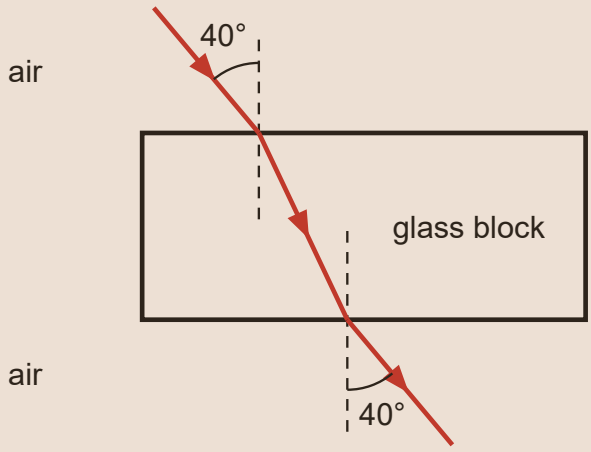
Draw or describe a refraction ray diagram

2 to 3 marks | Grade 5

1. Draw the normal where the ray meets the boundary.
2. Decide whether the wave speeds up or slows down.
3. Bend the ray towards the normal if it slows down, away if it speeds up.

Example. A ray of light passes from air into a rectangular glass block at an angle of incidence of 40°. Describe the path of the ray as it enters and then leaves the block.

Model answer.



Towards the normal going in, away from the normal coming out; the ray leaves parallel to the one that went in.

As it enters the glass the ray bends towards the normal, so the angle of refraction is less than 40° (1). As it leaves the block into air it bends away from the normal (1). The ray leaving the block is parallel to the ray that entered it (1).

Explain refraction using wave fronts

3 marks | Grade 7

1. Say which part of the wave front reaches the boundary first.
2. Say that part slows down while the rest is still moving faster.
3. Conclude that the wave front changes direction (bends towards the normal).

Example. Light waves travel from air into glass, where they travel more slowly. The wave fronts meet the boundary at an angle.
Explain why the light changes direction.

Model answer. One end of each wave front enters the glass first (1). That end slows down while the rest of the wave front is still in air, travelling faster (1). So the wave front changes direction, bending towards the normal (1).

Describe the method for the infrared practical 4 marks **Grade 5**

1. Say how every surface is kept at the same temperature (hot water in a Leslie cube).
2. Say what you use to measure the infrared (a detector) and what you keep the same (the distance).
3. Say how you compare the surfaces.

Example. Describe how a student could use a Leslie cube to find which type of surface emits the most infrared radiation.

Model answer. Fill the Leslie cube with hot water (1). Place an infrared detector a fixed distance from one face and record the reading (1). Repeat for each of the other faces, keeping the distance the same (1). The face with the highest reading emits the most infrared (1).

Explain why a variable must be controlled 2 marks **Grade 5**

1. Say how the variable would affect the reading.
2. Say that controlling it means only the type of surface affects the result (a fair test).

Example. Suggest why the infrared detector must be the same distance from each face of the Leslie cube.

Model answer. The reading depends on the distance: more infrared reaches the detector when it is closer to the surface (1). Keeping the distance the same means only the type of surface affects the reading (1).

Don’t lose marks

- Measuring angles from the boundary instead of from the normal.
- Saying light bends 'because the glass is denser' without mentioning the change in speed. The reason is the change in speed.
- Saying a ray along the normal bends. It does not change direction, although its speed changes.
- In the practical, not keeping the distance between the detector and each face the same.
- Saying shiny surfaces are good absorbers. Shiny surfaces reflect most of the infrared.

More tips

Memory tricks

- FAST: Faster → Away from the normal; Slower → Towards the normal.
- Picture a line of marchers walking at an angle from a road onto mud: the first ones onto the mud slow down, so the whole line swings round.
- Infrared practical in two words: matt black wins (best emitter and best absorber).

Exam technique

- Use a ruler and a sharp pencil for ray diagrams, and draw the normal as a dashed line.
- In any explanation of refraction, mention the change in speed.
- In wave front answers, say which part of the wave front slows down first and what the rest of the wave front is doing.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 — **Name what substances can do to EM waves**
A substance can absorb, transmit, refract or reflect EM waves.

Grade 4 — **State what causes refraction**
Refraction happens because the wave changes speed when it enters a different substance.

Grade 5 — **Draw a ray diagram for refraction**
Draw the normal; a ray that slows down (e.g. air into glass) bends towards the normal.

Grade 5 — **State which surfaces emit and absorb infrared best**
Matt black surfaces are the best emitters and absorbers of infrared; shiny silver surfaces are the worst.

Grade 5 — **Describe the infrared radiation practical**
Fill a Leslie cube with hot water and measure the infrared from each face with a detector at the same distance.

Grade 7 — **Explain refraction using wave fronts**
The part of a wave front that reaches the slower medium first slows down first, so the wave front changes direction.

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