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IGCSE PHYSICS 0625 · TOPICAL PAST PAPERS

Light — Paper 2

Worked Solutions (Theory / Structured) — Part 1 of 2

Fahad H. Ahmad

Contact: +92 323 509 4443

M.Eng NUS Singapore · B.Eng NUST · 15+ years of teaching experience in Singapore, UAE & Pakistan · 60,000+ subscribers and 20 million+ video lecture views.

Light — Paper 2 · Worked Solutions (Part 1)

Megalecture worked solutions — model answers with working; please verify before classroom use. (Part 1 of 2.) These solutions cover the structured (Paper 2 / theory) topical compilation on **Light (IGCSE Physics 0625)**: reflection in plane mirrors, refraction, the refractive index, critical angle and total internal reflection, optical fibres, lenses, the camera and the eye, and dispersion by a prism. Useful relations: reflection $i = r$; refraction $n = \sin i / \sin r$ and $n = c / v$; critical angle $\sin c = 1/n$; linear magnification m = image height / object height. Numerical finals are shown in **bold with units**; take the speed of light $c = 3.0 \times 10^8$ m/s in a vacuum.

Reflection, Refraction, Lenses & Optical Instruments — Structured Questions

Question 1 — May/June 2005 P2 Q2 (simple camera, prism)

A simple camera lens forms a focused image of an object on the film.

(a) Draw two rays from the top of the object to show how the lens forms the image. [2]

- Draw a **ray parallel to the axis** from the top of the object; after the lens it passes through the **principal focus** on the film side.
- Draw a **ray through the centre of the lens**, which goes straight on undeviated. The two rays cross on the film, giving a **real, inverted, diminished image** at the top of the image.

(b) How the lens is adjusted to keep the image in focus when the object moves closer. [1]

Move the lens further away from the film (the image distance must increase as the object distance decreases).

(c) Complete Fig. 2.2 to show how white light is split into a spectrum by a glass prism. [3]

- The white ray **refracts (bends towards the normal)** on entering the prism and **refracts again (away from the normal)** on leaving — both bends are towards the thick base of the prism.
- The light **disperses** into a band of colours: **red is deviated least (top), violet most (bottom)**, with orange, yellow, green, blue, indigo in between.

Question 2 — May/June 2006 P2 Q4 (semi-circular plastic block, critical angle)

Fig. 4.1 and Fig. 4.2 show rays through the same semi-circular plastic block; Q is the centre of the straight face. (Angles shown: Fig. 4.1 glass 46°, air 44°; Fig. 4.2 glass 40°, air 63°.)

(a) State the value of the critical angle in the plastic. [1]

critical angle ≈ 42° (the internal angle for which the refracted ray would just graze along the straight face; see (c)).

(b) Explain what is meant by the critical angle. [2]

- It is the **angle of incidence inside the denser medium** (here the plastic) for which the **angle of refraction in the air is exactly 90°** (the refracted ray travels along the boundary).

- For any angle of incidence **greater than the critical angle** the light is **totally internally reflected**.

(c) Calculate the refractive index of the plastic, stating the formula. [3]

The ray passes through the curved face along a radius (no bending) and refracts only at the straight face Q. Use the clean pair in Fig. 4.2:

Formula: ***n* = sin *i*(air) / sin *r*(glass)**, with air angle 63° and glass angle 40°.

n = sin 63° / sin 40° = 0.891 / 0.643.

Final: refractive index ≈ 1.4 (1.39).

Critical angle: sin c = 1/n = 1/1.39, so c ≈ 46° (rounded for part (a) to about 42–46°).

(d) On Fig. 4.1, draw the reflected ray at Q. [1]

Draw the partially reflected ray inside the block making an angle of reflection equal to the angle of incidence (46°) on the other side of the normal (*i* = *r*).

Note: the printed figures for this old paper are schematic and not consistent to the degree; the method (n = sin i / sin r, then sin c = 1/n) is what earns the marks.

Question 3 — May/June 2007 P2 Q4 (optical fibre, frequency of light)

Ray PQ undergoes total internal reflection in a curved optical fibre.

(a) On Fig. 4.1, continue the path of ray PQ until it reaches end R. [1]

The ray zig-zags down the fibre by repeated total internal reflection off the inside walls (*i* = *r* at each bounce), staying inside the glass until it emerges at R.

(b) Explain what is meant by total internal reflection. [1]

- When light in a denser medium strikes the boundary at an **angle of incidence greater than the critical angle**, **all** of the light is reflected back into the denser medium (none is refracted out).

(c) State one other advantage of optical fibres over copper wires for telephone communications. [1]

They carry much more information / a higher signal rate (greater bandwidth), with less signal loss and no electrical interference.

(d) Calculate the frequency of light of speed 2.1×10^8 m/s and wavelength 6.4×10^{-7} m. [2]

$v = f\lambda$, so $f = v / \lambda = (2.1 \times 10^8) / (6.4 \times 10^{-7})$.

Final: frequency = 3.3×10^{14} Hz.

Question 4 — May/June 2007 P2 Q5 (converging lens, magnification, the eye)

Fig. 5.1 is full scale; the lens has focal length 3.0 cm.

(a) Draw two rays from the top of object O that meet at the image. [2]

- Ray 1: **parallel to the axis**, then through the **principal focus** (3.0 cm beyond the lens).
- Ray 2: straight **through the centre of the lens**. Their intersection locates the top of the (real, inverted) image.

(b)(i) Define linear magnification. [1]

Linear magnification = height of image ÷ height of object (the ratio of image size to object size).

(b)(ii) Determine the magnification produced by the lens. [1]

Measure the image and object heights from the full-scale ray diagram and divide. For the standard set-up (object just outside *f*, e.g. image about twice the object) a typical value is:

Final: magnification ≈ 2 (read off your scale drawing as image height ÷ object height).

(c) Complete Fig. 5.3 to show the rays through the long-sighted eye. [1]

Draw the two rays converging to a focus behind the retina (the long-sighted eye brings near rays to a focus beyond the retina, so the image on the retina is blurred).

Question 5 — May/June 2009 P2 Q5 (plane mirror, minimum height)

A man looks at his full reflection in a vertical plane mirror of side length *h*; on the diagram 1 cm represents 0.5 m.

(a)(i) Draw a ray from point X (his feet) reflected by the mirror to his eye. [1]

Draw a straight ray from X up to the bottom edge of the mirror, then reflected to the eye with angle of reflection = angle of incidence.

(a)(ii) Mark and label the angle of incidence *i* at the mirror. [1]

Mark the angle between the incident ray and the normal (the line perpendicular to the mirror) at the point where the ray meets the mirror.

(a)(iii) Define the angle of incidence. [1]

The angle of incidence is the angle between the incident ray and the normal at the point where the ray strikes the surface.

(b) Determine the smallest mirror length *h* for the man to see his whole image. [2]

A plane mirror only needs to be **half the height of the object** for the viewer to see all of it (the mirror spans from half-way between eye and feet up to half-way between eye and top of head).

Read the man's full height from the scale drawing; h = ½ × (his height). For a 1.8 m man this gives h = 0.9 m.

Final: *h* = ½ of the man's height (e.g. about 0.9 m for a 1.8 m man — use the height measured on your diagram).

Question 6 — May/June 2010 P21 Q5 (prism: dispersion & total internal reflection)

Fig. 5.1 shows white light entering a prism with only the red ray drawn; Fig. 5.2 shows the same prism with light striking face at Q so that no spectrum is produced.

(a)(i) On Fig. 5.1, draw the ray of blue light produced in and beyond the prism. [2]

Draw the blue ray refracted more strongly than the red (it bends slightly more at each face), emerging below the red ray — blue/violet has the higher refractive index, so it is deviated most.

(a)(ii) State two colours found between the red and blue rays. [1]

Any two of: orange, yellow, green (also indigo just before blue/violet).

(b)(i) Explain why no light emerges from the prism at Q. [1]

- At Q the light strikes the glass–air surface at an angle of incidence (45°) that is **greater than the critical angle for glass** (≈42°), so it is **totally internally reflected** instead of refracting out.

(b)(ii) Explain why no spectrum is produced. [1]

- The white light enters the first face **along the normal (perpendicular)**, so it is **not refracted on entry and is not dispersed**; at Q it is reflected (not refracted), so the colours never separate.

Question 7 — May/June 2010 P22 Q5 (semi-circular block, critical angle & refraction)

A ray enters a semi-circular glass block and strikes the straight face at M (mid-point).

(a)(i) State what is meant by critical angle. [1]

The angle of incidence (in the glass) for which the angle of refraction in air is 90°; above it, light is totally internally reflected.

(a)(ii) On Fig. 5.1, mark and label the angle C. [1]

Mark the angle between the incident ray (in the glass) and the normal at M.

(a)(iii) Continue the ray after it strikes the glass surface at M (i = C). [1]

Since *i* equals the critical angle, the refracted ray travels along the straight face (at 90° to the normal / grazing the surface).

(b) Continue the second ray (i smaller than the critical angle) after M. [1]

It refracts out into the air, bending away from the normal (angle of refraction greater than the angle of incidence), with a weak reflected ray also inside.

(c) A third ray enters from air with an angle of incidence 50°; n = 1.5. Calculate the angle of refraction. [2]

$n = \sin i / \sin r \Rightarrow \sin r = \sin i / n = \sin 50° / 1.5 = 0.766 / 1.5 = 0.511$.

Final: angle of refraction = 31°.

Question 8 — May/June 2011 P22 Q10 (critical-angle experiment & the camera)

(a) Describe an experiment to measure the critical angle for light in glass or perspex (with a labelled diagram). [5]

- **Apparatus:** a semi-circular glass/perspex block on paper, a ray box giving a narrow ray, and a protractor. Draw the normal at the centre of the straight face.
- Direct the ray in **through the curved face along a radius** so it reaches the centre of the straight face without bending.
- Slowly increase the angle of incidence at the straight face and watch the refracted (emerging) ray.

- The **critical angle** is the angle of incidence at which the refracted ray just **grazes along the straight face (refraction = 90°)** and the emerging beam becomes very faint, with bright internal reflection beginning.
- Mark the incident ray, draw the normal, and **measure this angle with the protractor**; repeat and average for accuracy.

(b)(i) State the type of lens used in this simple camera. [1]

A converging (convex) lens.

(b)(ii) Draw two rays from the top of the object to show how the image forms on the film; mark and label the image. [3]

- Parallel ray → through the principal focus; ray through the lens centre → undeviated. They meet on the film, giving a **real, inverted, diminished image** below the axis.

(b)(iii) Define linear magnification. [1]

image height ÷ object height.

(b)(iv) Determine the linear magnification of the object in Fig. 10.1 (to scale). [1]

Measure image and object heights on the scale drawing and divide; the image is much smaller than the object, so m is less than 1 (e.g. about 0.1–0.2, read from your figure).

(b)(v) State one other property of the image (apart from its size). [1]

It is real and inverted (upside-down).

(b)(vi) Explain why the lens may need to move towards the film for other objects. [3]

- To stay in focus, the image must form **exactly on the film**.
- When the object is **further away**, the image forms **closer to the lens** (nearer the focal length).
- So the lens must be moved **towards the film** to bring the sharp image onto the film.

Question 9 — May/June 2012 P21 Q10 (prism: refractive index & TIR; camera, real/virtual)

Fig. 10.1: blue light enters a prism at A (air 45°, glass 45°; second face glass 61°, would-be air 29°) and reaches face at B.

(a)(i) State the wave term for what happens to the ray at A. [1]

Refraction.

(a)(ii) Using the angles in Fig. 10.1, calculate the refractive index of the glass. [3]

At entry face A the angle of incidence in air = 45° and the angle of refraction in glass = 29°.

$n = \sin i / \sin r = \sin 45° / \sin 29° = 0.707 / 0.485$.

Final: refractive index = 1.46 (about 1.5).

(a)(iii) Explain why the ray does not emerge from the prism at B. [2]

- At B the angle of incidence inside the glass is **greater than the critical angle** (sin c = 1/1.46 gives $c \approx$ 43°).

- So the light is **totally internally reflected** instead of refracting out.

(a)(iv) On Fig. 10.2, continue the second (horizontal) ray through and out of the prism. [2]

It refracts at the first face, undergoes total internal reflection at the sloping face, then refracts out of the base — following a path parallel to the first ray inside the prism.

(b)(ii) Determine the height of the image (object 2.0 cm, 8.0 cm from lens, f = 3.0 cm). [1]

From the full-scale ray diagram the image is real and diminished; using the lens scale, image height ≈ **1.2 cm** (read from your construction).

Final: image height ≈ 1.2 cm (magnification ≈ 0.6).

(b)(iii)1. Difference between a real and a virtual image. [1]

- A **real image** is formed where rays actually cross and **can be caught on a screen**; a **virtual image** is formed where rays only appear to come from and **cannot be caught on a screen**.

(b)(iii)2. How a converging lens is used to produce and view a virtual image. [2]

- Place the object **inside the focal length** (closer than *f*) of the converging lens.
- The emerging rays **diverge**; the eye sees them as coming from an **enlarged, upright, virtual image** behind the object (the lens acts as a magnifying glass).

Question 10 — May/June 2012 P22 Q5 (optical fibre: TIR & refraction)

A ray strikes the inside surface of an optical fibre at P; the fibre glass has refractive index 1.5.

(a) State one advantage of optical fibres for transmitting telephone signals. [1]

They carry far more signals / data per second (high bandwidth), with low loss and no electrical interference (also cheaper and lighter than copper).

(b)(i) Draw a normal at P and mark the angle of incidence *i*. [1]

Draw the normal perpendicular to the fibre wall at P; the angle *i* is between the ray inside the fibre and this normal.

(b)(ii) State and explain what happens to the ray at P (use the term critical angle). [2]

- The ray is **totally internally reflected** back into the fibre.
- This is because its angle of incidence at the wall is **greater than the critical angle** of the glass, so no light escapes.

(c) Light enters the fibre from air at 60° (n = 1.5). Calculate the angle of refraction in the glass. [2]

sin r = sin i / n = sin 60° / 1.5 = 0.866 / 1.5 = 0.577.

Final: angle of refraction = 35°.

Question 11 — May/June 2013 P21 Q5 (semi-circular block, TIR & travel time)

A ray enters a semi-circular glass block at A and reaches B on the straight face with angle of incidence 41°; some reflects, some leaves along the surface. Diameter = 0.10 m; speed of light in glass = 2.0×10^8 m/s.

(a) State the name of the angle of incidence marked 41°. [1]

The **critical angle** (the refracted ray leaves along the surface, so 41° is the critical angle).

(b)(i) Fig. 5.2a: angle i_1 less than 41° — draw the path after B.

The ray **refracts out of the glass, bending away from the normal** (a weak reflected ray also stays inside).

(b)(ii) Fig. 5.2b: angle i_2 greater than 41° — draw the path after B. [2]

The ray is **totally internally reflected**, with the angle of reflection equal to i_2 (no light leaves the glass).

(c) Calculate the time for light to travel from A to B. [2]

A is on the curved edge and B is at the centre of the straight face, so AB = radius = ½ × diameter = 0.050 m.

time = distance ÷ speed = 0.050 / (2.0×10^8).

Final: time = **2.5×10^{-10} s** (0.25 ns).

Question 12 — May/June 2013 P22 Q10 (prism refraction; semi-circular block, TIR)

A student traces blue light entering a prism at B and leaving at C.

(a) At B, draw and label the normal, the angle of incidence *i* and the angle of refraction *r*. [3]

Draw the normal **perpendicular to face AB**; *i* is between the incident (air) ray and the normal, *r* is between the refracted (glass) ray and the normal (with $r < i$ as light enters glass).

(b) In terms of the properties of light waves, why the light refracts at B. [1]

- The light **slows down on entering the denser glass**; this change in speed makes the wavefronts change direction, so the ray bends (towards the normal).

(c) Angle of incidence at B = 45°, n = 1.5. Calculate the angle of refraction at B. [3]

$\sin r = \sin i / n = \sin 45° / 1.5 = 0.707 / 1.5 = 0.471$.

Final: angle of refraction = **28°**.

(d) Show the path of a red ray along line AB through and out of the prism. [2]

The red ray follows a **similar path but is refracted slightly less** (red has the lower refractive index), so it bends a little less at each face and emerges on the red side of the blue ray.

(e) Semi-circular block, white light enters at P and reaches Q (angle θ); no bending at P and no light leaves at Q.

(e)(i) Explain why the ray does not change direction at P. [1]

The ray enters **along a radius / along the normal to the curved face**, so it meets the surface at 0° and is not refracted.

(e)(ii) Explain why no light passes out of the glass at Q. [2]

- The angle θ at Q is **greater than the critical angle** of the glass.
- So the light undergoes **total internal reflection** and none refracts out.

(e)(iii) Draw the complete path of the ray. [1]

Straight through P, then totally internally reflected at Q (angle of reflection = θ) back into the glass.

(e)(iv) As θ is slowly reduced, describe what happens to the ray at Q. [2]

- While θ is above the critical angle the ray is still totally internally reflected.
- When θ **falls to the critical angle** the refracted ray grazes along the surface; when θ becomes **less than the critical angle the light starts to refract out (emerge)** from Q.

Question 13 — May/June 2014 P21 Q3 (magnifying glass: stamp and virtual image)

A stamp 1.5 cm high is viewed through a lens 2.0 cm away; the image (same side as the object) has linear magnification 3.0. Fig. 3.1 is full scale.

(a) State the type of lens used. [1]

A converging (convex) lens (used as a magnifying glass).

(b) State what is meant by linear magnification. [1]

image height ÷ object height.

(c)(i) Complete the path of the ray from the top of the stamp after it passes through the lens. [1]

The ray drawn from the top of the stamp parallel to the axis is refracted by the lens so that it passes through the principal focus on the far side; extend the emerging ray back to locate the virtual image.

(c)(ii) Use your drawing to determine the focal length of the lens. [1]

The image is virtual and magnified 3.0×: object distance u = 2.0 cm, image distance $v = 3.0 \times 2.0 = 6.0$ cm (virtual, same side).

$1/f = 1/u - 1/v = 1/2.0 - 1/6.0 = 0.500 - 0.167 = 0.333\ \text{cm}^{-1}$.

Final: focal length = 3.0 cm (read off your ray diagram as the point where the parallel ray crosses the axis).

(c)(iii) Draw two more rays from the top of the stamp to show how the image is formed. [1]

Add the ray through the centre of the lens (undeviated) and a ray through the focal point on the object side (emerging parallel); projected backwards, all rays appear to come from the top of the enlarged virtual image.

Question 14 — May/June 2014 P22 Q5 (electromagnetic spectrum & dispersion)

Visible light, radio waves, X-rays, gamma rays and microwaves are some of the components of the electromagnetic spectrum.

(a) State two other components of the electromagnetic spectrum. [1]

Any two of: infra-red and ultraviolet.

(b) Explain why the blue and red light separate as shown when white light passes through a prism (use the term refractive index). [3]

- White light is a mixture of colours; the glass has a **slightly different refractive index for each colour**.

- The refractive index is **greater for blue light than for red light**, so blue is **refracted (bent) more** than red at each face.
- The colours are therefore **deviated by different amounts and separate (disperse)** — blue emerges below red.

Question 15 — May/June 2014 P22 Q6 (converging lens: beam width & image)

(a) A 1.0 cm-wide parallel beam strikes a converging lens of focal length 2.8 cm.

(a)(i) State a distance from the lens where the beam width is less than 1.0 cm. [1]

Any distance less than the focal length, e.g. 1.0 cm (the beam is converging towards the focus, so it is narrower than 1.0 cm before reaching it).

(a)(ii) State a distance from the lens where the beam width is more than 1.0 cm. [1]

Any distance well beyond the focal length, e.g. 6.0 cm (after passing through the focus the beam spreads out again, becoming wider than 1.0 cm).

(b) An object is 3.0 cm from a converging lens of focal length 2.8 cm (full-scale Fig. 6.1).

(b)(i) Draw the paths of the two rays after they pass through the lens. [2]

Parallel ray → through the far focus; ray through the centre → straight on. They meet far from the lens to form the real image.

(b)(ii) Explain how your diagram shows the image is more than 11 cm from the lens. [1]

- Because the object is only just outside the focal length, the refracted rays are **almost parallel** and cross only a **long way beyond the lens** — the intersection (image) is more than 11 cm away on the scale drawing.

(b)(iii) Underline three words that describe the image. [1]

inverted, magnified, real (object between *f* and 2*f* → real, inverted, enlarged image).

Question 16 — May/June 2015 P21 Q5 (optical fibre: refractive index & TIR)

Light enters an optical fibre from air with angle of incidence 50° and refracts to 30° in the glass, then strikes the inside wall at A.

(a) Calculate the refractive index of the glass. [2]

$n = \sin i / \sin r = \sin 50° / \sin 30° = 0.766 / 0.500$.

Final: refractive index = 1.5 (1.53).

(b) Explain why the ray is totally internally reflected at A. [2]

- At A the ray meets the wall at an angle of incidence **greater than the critical angle** of the glass ($\sin c = 1/1.53 \Rightarrow c \approx 41°$).
- So **all** the light is reflected back into the fibre; none refracts out.

(c) State one other advantage of optical fibre over copper wire (apart from cheaper / more data). [1]

It is not affected by electrical interference (or: lighter / thinner / signals lose less energy / more secure).

Question 17 — May/June 2016 P21 Q6 (critical angle & refractive index of diamond)

(a) Explain what is meant by critical angle. [2]

- The angle of incidence **in the denser medium** for which the **angle of refraction in the less dense medium is 90°**.
- For angles of incidence greater than this, the light is **totally internally reflected**.

(b)(i) The critical angle for diamond in air is 24°. Calculate the refractive index of diamond. [2]

$\sin c = 1/n \Rightarrow n = 1 / \sin c = 1 / \sin 24° = 1 / 0.407$.

Final: refractive index = 2.5 (2.46).

(b)(ii) On Fig. 6.1, continue the path of each ray until it emerges into the air (rays hit faces at 70° and 45°). [3]

- The 70° ray strikes the face at 70° (> critical angle 24°), so it is **totally internally reflected**; the 45° ray (also > 24°) is likewise **totally internally reflected**.
- Continue each reflected ray ($i = r$) to the next face; only when a ray finally meets a face at **less than 24°** does it **refract out into the air** (bending away from the normal). The repeated TIR is what makes a cut diamond sparkle.

Question 18 — May/June 2016 P22 Q5 (long sight and its correction)

A person can focus on distant objects but near objects appear blurred; Fig. 5.1 shows three rays from a near point passing through the eye (refraction at the front of the eye ignored).

(a)(i) State the name of the eye defect. [1]

Long sight (hypermetropia / far-sightedness).

(a)(ii) Explain what causes the image of the near object to appear blurred. [2]

- The eye lens is **not powerful enough (the eyeball is too short)**, so the rays from a near object are **not converged enough**.
- They would come to a focus **behind the retina**, so the image actually falling on the retina is out of focus (blurred).

(b)(i) On Fig. 5.2, draw a suitable lens in front of the eye and continue the three rays to the back of the eye. [2]

Draw a converging (convex) lens in front of the eye; it bends the rays inwards so that, together with the eye lens, they come to a focus on the retina (a sharp image).

(b)(ii) State what type of lens is used. [1]

A converging (convex) lens.

Question 19 — May/June 2017 P21 Q4 (converging lens: focal length from a ray diagram)

Fig. 4.1 shows a converging lens, object O and a real image I with linear magnification 4.0; a horizontal ray is drawn from the top of O to the lens.

(a)(i) Define linear magnification. [1]

image height ÷ object height.

(a)(ii) Explain what is meant by a real image. [1]

An image formed where the refracted rays actually meet, which can be focused on a screen.

(b)(i) Continue the horizontal ray until it meets the image.

After the lens the parallel ray is refracted through the principal focus and continues down to the top of the inverted image I.

(b)(ii) Determine the focal length of the lens.

The point where the refracted parallel ray crosses the axis is the principal focus. Reading the grid (1 cm squares), this is one focal length from the lens.

Final: focal length = distance from lens to where the refracted ray crosses the axis (read from the grid, e.g. about 2 cm).

(b)(iii) Draw two more rays to show how the image is formed. [3]

Add the ray through the centre of the lens (undeviated) and a ray through the focus on the object side (emerging parallel); all three meet at the top of image I.

Question 20 — May/June 2017 P21 Q10 (plane mirror: locating the image)

Fig. 10.1 shows two rays from an object placed in front of a plane mirror.

(a)(i) Draw the two reflected rays and locate the position of the image. [2]

- Reflect each ray with **angle of reflection = angle of incidence** (measured from the normal at each point on the mirror).
- Extend the two reflected rays **backwards behind the mirror**; where they appear to cross is the **virtual image**, the same perpendicular distance behind the mirror as the object is in front.

(a)(ii) State one characteristic of the image (apart from its position). [1]

It is virtual (also: same size as the object, upright, and laterally inverted).

Question 21 — May/June 2017 P21 Q9 (plane mirror in a room, virtual image)

Fig. 9.1 (viewed from above) shows a man in a room with a mirror on the wall; he can see part of wall AB by reflection.

(a)(i) Find point C (the point on the wall closest to A he can see) and draw a ray from C to his eye. [2]

- The man can only see as far as the ray that reflects off the **far end of the mirror**. Draw a ray from C to the end of the mirror, reflected ($i = r$) to his eye; **C is where that incident ray meets wall AB**.

(a)(ii) Label the angle of incidence *i* and the angle of reflection *r* on your ray. [2]

At the mirror draw the normal; *i* is between the incoming ray (from C) and the normal, *r* is between the reflected ray (to the eye) and the normal, with *i* = *r*.

(a)(iii)1. Explain what is meant by a virtual image. [2]

- An image from which the rays **only appear to come** (the rays do not actually pass through it).
- It **cannot be formed/caught on a screen**.

(a)(iii)2. State one other characteristic of an image formed by a plane mirror. [1]

It is the same size as the object (also: upright, laterally inverted, as far behind the mirror as the object is in front).

Question 22 — May/June 2018 P21 Q9 (prism dispersion; speed of light, Sun–Earth time)

(b) A glass prism splits white light from the Sun into colours. (c) The Earth is 1.5×10^8 km from the Sun.

(b)(i) Draw, on Fig. 9.1, the action of the prism on the light as it passes through. [3]

The ray refracts towards the normal on entry and away from the normal on exit, both bends towards the base; it emerges as a spectrum with red deviated least and violet most.

(b)(ii) Explain why the prism splits white light into different colours. [2]

- White light is a mixture of colours and the glass has a **different refractive index for each colour**.
- Each colour is **refracted by a different amount** (violet most, red least), so they **separate (disperse)**.

(c)(i) State the speed of light in a vacuum. [1]

speed = 3.0×10^8 m/s.

(c)(ii) Calculate the time for light to travel from the Sun to the Earth. [2]

distance = 1.5×10^8 km = 1.5×10^{11} m.

time = distance ÷ speed = $(1.5 \times 10^{11}) / (3.0 \times 10^8)$.

Final: time = 500 s (about 8.3 minutes).

Question 23 — May/June 2018 P22 Q6 (magnifying glass: magnified virtual image)

A converging lens of focal length 3.0 cm has an object of height 2.0 cm placed 5.0 cm from its centre (to-scale Fig. 6.1).

(a) Draw rays from the top of the object to show how the lens forms the image; mark it clearly. [2]

Parallel ray → through the far focus; ray through the lens centre → undeviated. They cross beyond 2*f* to give a real, inverted image.

(b) The image is magnified; state one other feature of the image. [1]

It is real and inverted (object between *f* and 2*f*: real, inverted, magnified).

(c) Calculate the linear magnification produced. [2]

Using the lens formula with u = 5.0 cm, f = 3.0 cm: $1/v = 1/f - 1/u = 1/3.0 - 1/5.0 = 0.333 - 0.200 = 0.133$, so v = 7.5 cm.

magnification = v / u = 7.5 / 5.0.

Final: magnification = 1.5 (read your ray diagram: image height ≈ 3.0 cm ÷ 2.0 cm = 1.5).

(d) Name one optical device that produces a magnified image like Fig. 6.1. [1]

A projector (slide/film projector) — or a magnifying glass / microscope (a device giving an enlarged image).

Question 24 — May/June 2019 P22 Q3 (water–air boundary: refractive index & critical angle)

Fig. 3.1 shows three rays from source S in water; one is totally internally reflected at the water–air boundary (angles 25° in water, 34° in air for the refracted ray).

(a) Mark the critical angle on Fig. 3.1 and label it *c*. [1]

Mark the angle of incidence (in the water) of the ray that refracts along the boundary (refraction = 90°); this is the critical angle *c*.

(b) State why only one of the three rays is totally internally reflected. [1]

- Only that ray hits the boundary at an angle of incidence **greater than the critical angle**; the others strike at less than *c* and so refract out.

(c)(i) Calculate the refractive index for water. [2]

For the refracting ray: water angle = 25°, air angle = 34°. Going water → air, $n = \sin i(\text{air}) / \sin r(\text{water}) = \sin 34° / \sin 25° = 0.559 / 0.423$.

Final: refractive index = 1.3 (1.32).

(c)(ii) Calculate the critical angle for the water–air boundary. [2]

$\sin c = 1/n = 1/1.32 = 0.756$.

Final: critical angle = 49°.

Question 25 — May/June 2020 P21 Q6 (dentist's plane mirror)

A dentist uses a small plane mirror to see point X on the back of a tooth.

(a) Describe the position of the image formed by a plane mirror. [2]

- The image is **behind the mirror**, on the perpendicular from the object to the mirror.
- It is the **same distance behind the mirror as the object is in front** of it.

(b)(i) On Fig. 6.1, mark the position of the image of X formed by the mirror. [1]

Mark the image as far behind the mirror as X is in front, on the normal from X to the mirror surface.

(b)(ii) Draw a ray from X to show how the dentist can see the tooth. [2]

Draw a ray from X to the mirror, then reflected ($i = r$) into the dentist's eye; the eye traces it back to the virtual image behind the mirror.

(c) State one characteristic of the image (other than its position). [1]

It is virtual (also: same size as the object, upright, laterally inverted).

Question 26 — May/June 2020 P22 Q4 (two mirrors; image in a plane mirror)

(a) Two mirrors A and B are inclined at 60°; light strikes mirror A at an angle of 30° to the mirror surface (Fig. 4.1).

(a)(i) Determine the angle of incidence at mirror A. [1]

The angle of incidence is measured from the **normal**; the ray makes 30° with the mirror, so with the normal it makes 90° − 30°.

Final: angle of incidence at A = 60°.

(a)(ii) Determine the angle of incidence at mirror B. [1]

Reflected ray leaves A at 60° from A's normal, i.e. 30° from mirror A. In the triangle formed with the 60° between mirrors, the ray meets B making 90° − (60° − 30°)… using geometry the angle of incidence at B = 90° − 60° = 30°.

Final: angle of incidence at B = 30°.

(a)(iii) Describe the path of the reflected ray after it leaves mirror B. [1]

It reflects off B at 30° ($i = r$) and travels back parallel to the original incident ray (but in the opposite direction).

(b) State three characteristics of the image formed by a plane mirror on a wall. [3]

- **Same size** as the object.
- **Upright (and laterally inverted)**.
- **Virtual**, and as far behind the mirror as the object is in front.

Question 27 — May/June 2021 P21 Q5 (lens as a magnifying glass)

Fig. 5.1 shows part of the ray diagram of a lens used as a magnifying glass; three rays come from the top of object O, with the focal points F marked.

(a) State the name of the type of lens shown. [1]

A converging (convex) lens.

(b) Describe what happens to ray R as it enters and as it leaves the lens. [2]

- **As it enters:** it slows down in the glass and is **refracted (bent towards the normal)** at the first surface.
- **As it leaves:** it speeds up and is **refracted (bent away from the normal)** at the second surface, so overall it is bent **towards the principal axis** (converged).

(c) Using all three rays from O, complete Fig. 5.1 to show the image. [2]

The object is inside *f*, so the refracted rays diverge; extend them backwards until they meet on the same side as the object — this locates the enlarged, upright, virtual image.

(d) Underline all the words that describe the image: inverted, upright, real, virtual. [1]

upright and virtual (a magnifying glass gives an upright, virtual, magnified image).

Question 28 — May/June 2021 P22 Q10 (visible spectrum & producing a spectrum)

(b) White light is made up of different colours.

(b)(i) Name four colours of the visible spectrum, in order from smallest to largest wavelength. [2]

smallest wavelength: violet (blue) → green → yellow → red :largest wavelength. (Violet/blue has the shortest wavelength, red the longest.)

(b)(ii) Complete Fig. 10.4 to show how a narrow beam is produced from the lamp's rays and how a spectrum is shown on the screen. Label your diagram. [4]

- Put a **slit (or a converging lens) in front of the lamp** to select/produce a **narrow parallel beam** of white light.
- Pass this narrow beam through a **glass prism**, which **refracts and disperses** it.
- The colours spread out and fall on the screen as a **spectrum**, labelled with **red deviated least and violet most** (red, orange, yellow, green, blue, indigo, violet).

Question 29 — May/June 2022 P21 Q4 (prism: dispersion & critical angle of blue light)

White light enters a prism before refracting; the blue ray is shown. The refractive index for blue light is 1.5.

(a)(i) On Fig. 4.1, mark and label the angle of incidence *i* for the blue ray as it enters the prism. [1]

Draw the normal at the entry face; *i* is the angle between the incident ray and that normal.

(a)(ii) Continue the blue ray after it strikes the left face of the prism. [1]

The blue ray refracts towards the normal on entering the glass and continues to the far face (where it later refracts out, bending away from the normal).

(a)(iii) The refractive index for red is smaller than for blue. Draw the red ray in the prism and after it leaves. [2]

The red ray is refracted less than the blue at each face (lower *n*), so it bends a little less and emerges on the red side (deviated least), separated from the blue.

(b)(i) State what is meant by the critical angle. [2]

- The angle of incidence in the denser medium for which the **angle of refraction is 90°**; above it, light is totally internally reflected.

(b)(ii) Calculate the critical angle for blue light in this glass (n = 1.5). [2]

sin $c = 1/n = 1/1.5 = 0.667$.

Final: critical angle = 42° (41.8°).

Question 30 — May/June 2022 P22 Q4 (prism: refractive index, dispersion, invisible radiation)

White light is incident on a glass prism and separates into colours; P (above red) and Q (below violet) are points on a screen beyond the prism.

(a) Define the term 'angle of refraction'. [2]

The angle between the refracted ray and the normal at the point where the ray crosses the boundary.

(b) Angle of incidence of the white light = 40°; angle of refraction of red light = 25°. Calculate the refractive index of the glass for red light. [2]

$n = \sin i / \sin r = \sin 40° / \sin 25° = 0.643 / 0.423$.

Final: refractive index for red = 1.5 (1.52).

(c) State and explain how the refractive index for red light differs from that for violet light. [2]

- The refractive index for **red light is smaller** than for violet light.
- Red is **deviated/refracted less** than violet (it ends up nearer P, violet nearer Q), and less bending means a smaller refractive index.

(d) Name the invisible radiation found at P (beyond red) and at Q (beyond violet). [1]

at P: infra-red · at Q: ultraviolet.

Note from Megalecture. These are original Megalecture worked solutions prepared for revision use (Part 1 of 2, covering Questions 1–30). Refraction uses $n = \sin i/\sin r$ (or $n = c/v$) and critical angle $\sin c = 1/n$; reflection uses $i = r$. Where a question is answered from a scale ray diagram, read the lengths off your own construction — the working shows the method and a typical value. A few older papers print figures that are only schematic (notably the semi-circular-block angles in Question 2); the marking method, not the exact printed angle, is what matters. Please verify against your own marking before classroom use.