Unit 15 · Refraction at Plane Surfaces

HARDER PRACTICE QUESTIONS · ANSWER KEY

Full marks 35

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Spot the error

ANSWER U · 3

He treated the 1.2 m as the real depth and divided again. 1.2 m is already the **apparent** depth a. With $\mu = R/a$, the real depth is $R = \mu a = 1.33 \times 1.2 =$ **1.6 m**. The pool is deeper than it looks, which is why stepping into clear water is dangerous.

MARKING SCHEME

- ✓ The error: 1.2 m is the apparent depth, not the real depth.
- ✓ $\mu = R/a$, so $R = \mu a$.
- ✓ R = 1.6 m.

2 A lamp under water

ANSWER A · 4

i. Rays meeting the surface at more than the critical angle C are totally reflected back into the water; only those inside C get out, and they reach the surface within a circle round the point above the lamp.

ii. $\sin C = 1/1.33 = 0.752$, so $C = 48.8°$. The radius is $r = 2.0 \tan 48.8° = 2.0 \times 1.14 =$ **2.3 m**.

iii. $r = h \tan C$, so with 1.0 m of water the radius **halves**, to 1.14 m. A larger refractive index means a smaller C, so a **smaller** circle.

MARKING SCHEME

- ✓ Beyond the critical angle the light is totally reflected, so only rays inside C leave: a circle.
- ✓ $C = 48.8°$.
- ✓ $r = h \tan C = 2.3$ m.
- ✓ Half the depth halves the radius; a larger μ gives a smaller circle.

3 Check the readings

ANSWER HA · 4

(The readings are made up, from glass of refractive index 1.50 with small errors.)

i. 1.52, 1.50, 1.39, 1.51, 1.49.

ii. The reading at $i = 40°$ (1.39). With $\mu = 1.50$, $\sin r = \sin 40° \div 1.50 = 0.429$, so r should have been about **25.4°**.

iii. The average of the other four is **1.50**.

iv. The points lie on a straight line through the origin, whose slope is μ (the 40° point would lie off it).

MARKING SCHEME

- ✓ The five ratios 1.52, 1.50, 1.39, 1.51, 1.49.
- ✓ The 40° reading is the odd one; $r \approx 25.4°$.
- ✓ $\mu \approx 1.50$.
- ✓ A straight line through the origin, slope μ.

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4 How much light can a fiber take in?

ANSWER HA · 4

i. $\sin C = 1.40/1.50 = 0.933$, so $C = \mathbf{69.0}°$.

ii. A ray refracted at r inside the end face meets the side wall at $90° - r$. It is trapped if $90° - r \geq 69.0°$, that is $r \leq \mathbf{21.0}°$.

iii. At the end face, $\sin\theta = 1.50 \sin 21.0° = 1.50 \times 0.359 = 0.539$, so $\theta = \mathbf{32.6}°$. Light arriving within 32.6° of the axis is guided; steeper light leaks out through the cladding.

MARKING SCHEME

✓ $C = 69.0°$ from $\sin C = 1.40/1.50$.

✓ The angle at the wall is $90° - r$, so $r \leq 21.0°$.

✓ $\sin\theta = 1.50 \sin 21.0°$ (Snell's law at the end face).

✓ $\theta = 32.6°$.

5 Predict, then explain

ANSWER HA · 3

The part inside the liquid seems to **vanish**. We see a clear object only because light bends (refracts) and is partly reflected where it crosses the boundary between it and its surroundings. With equal refractive indices light travels at the same speed in both, so at the boundary $\sin i/\sin r = 1$: it goes straight on and none is reflected. Nothing marks the edge of the rod, so it can't be seen.

MARKING SCHEME

✓ The rod can't be seen in the liquid.

✓ Equal refractive indices: light crosses the boundary without bending ($\sin i = \sin r$).

✓ And without reflection, so nothing shows the rod's edge.

6 Check an approximation

ANSWER A · 3

Approximate: $i = 10° = 0.1745$ rad, $L \approx 5.0 \times 0.1745 \times (1 - 1/1.5) = \mathbf{0.291\ cm}$.

Exact: $\sin r = \sin 10° \div 1.5 = 0.116$, $r = 6.65°$; $L = 5.0 \sin 3.35° \div \cos 6.65° = 5.0 \times 0.0585 \div 0.993 = \mathbf{0.294\ cm}$.

The approximation is about **1% low**: good for small angles.

MARKING SCHEME

✓ $L \approx 0.291$ cm.

✓ Exact $L = 0.294$ cm ($r = 6.65°$).

✓ About 1% different.

7 Estimate it

ANSWER A · 2

$v = c/\mu = 3 \times 10^8 \div 1.5 = 2 \times 10^8$ m/s, so $t = 5 \times 10^4 \div 2 \times 10^8 = 2.5 \times 10^{-4}$ s, **0.25 ms**. Through air ($v \approx c$) it would take 1.7×10^{-4} s, so about **0.08 ms** longer. (The real path zigzags a little, so it takes slightly longer still.)

MARKING SCHEME

✓ $t = 2.5 \times 10^{-4}$ s in the fiber.

✓ About 0.08 ms (half as long again) more than through air.

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8 Which explanation fits the evidence?

ANSWER HA · 3

Prapti's. Total internal reflection happens only for light meeting the glass–air surface at more than the critical angle, about 42°, so the crack shines brightly only from directions where such light is sent to the eye, exactly as seen. A shiny dusty surface would reflect only part of the light, and would show from many directions, not as a bright flash from a few.

MARKING SCHEME

- ✓ Prapti's explanation.
- ✓ TIR needs light from the glass (denser) to the air of the crack (rarer) at more than the critical angle, so the crack shines only from certain directions.
- ✓ A metal-like dusty surface would reflect only part of the light and not depend on direction this way.

9 Design an experiment

ANSWER A · 4

i. She draws round the block on the paper, draws a normal at a point on one face and an incident ray at an angle i to it, and sticks two pins on that ray. Looking through the opposite face, she sticks two more pins in line with the images of the first two, which marks the emergent ray. Removing the block, she joins the point of entry and the point of exit: the ray inside the glass.

ii. The angle of incidence i and the angle of refraction r inside the glass, with the protractor.

iii. $\mu = \sin i \div \sin r$.

iv. Repeat for several angles of incidence (say 30° to 60°) and average, or plot sin i against sin r and take the slope; place pins far apart and keep them upright.

MARKING SCHEME

- ✓ Outline of the block, normal, incident ray with two pins; two more pins in line with the images to mark the emergent ray; the ray through the glass joined.
- ✓ Measures i and r.
- ✓ $\mu = \sin i / \sin r$.
- ✓ Several angles, averaged or graphed.

10 Correct the misconceptions

ANSWER U · 3

1. Optical density is not mass per volume: light travels more slowly in kerosene ($\mu = 1.44$) than in water (1.33), so kerosene is optically **denser**.
2. The frequency stays the **same**; the speed (and wavelength) change, and the change of speed makes it bend.
3. Total internal reflection needs light going from a **denser** towards a rarer medium; light from air into glass is always refracted in, whatever the angle.

MARKING SCHEME

- ✓ Kerosene is optically denser (larger μ, slower light), whatever its mass per volume.
- ✓ The frequency doesn't change; the speed does.
- ✓ No TIR from air into glass: it needs denser to rarer.

11 Think

ANSWER HA · 2

Diamond's refractive index (2.42) gives a critical angle of only 24.4°, glass's about 42°. Inside the diamond, light meets the back faces at more than 24.4° and is totally reflected several times before coming out through the top in a few directions. In the glass copy much of that light meets the back faces at less than 42° and leaks out, so less light comes back to the eye.

MARKING SCHEME

- ✓ Diamond's critical angle (24.4°) is much smaller than glass's (about 42°).
- ✓ So in diamond far more light is totally reflected inside and comes out of the top; in glass more leaks out through the back.

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See it at Science Playground

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- **Rays of Light** (exhibit): Slant the block in a laser beam and read the angles on the scale: it bends towards the normal going in, away from it coming out.
- **The Ecosystem Pond** (exhibit): Look straight down at the pebbles on the pond's bottom: they seem nearer than they are, at the real depth divided by water's refractive index.
- **Total Internal Reflection** (exhibit): Inside each fiber the light meets the wall at more than the critical angle and is totally reflected, so it escapes only at the tip.
- **The Periscope** (exhibit): This periscope turns the light with two mirrors at 45°; one with totally reflecting prisms instead loses almost no light at the turns.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	6	13	16	**35**

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