Unit 13 · Light

ANSWER KEY · FOR TEACHERS

Full marks 44

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

1 Key words

1. optically denser → **d.** a medium in which light travels more slowly
2. normal → **e.** a line at right angles to the surface at the point of incidence
3. refractive index → **f.** speed of light in a vacuum ÷ speed of light in the medium
4. critical angle → **b.** the angle of incidence in the denser medium for which the angle of refraction is 90°
5. lateral shift → **g.** the perpendicular distance between the emergent ray and the incident ray produced
6. apparent depth → **a.** the distance below the surface at which an object seems to be

K · 3

Each carries 0.5 mark.

2 Label the diagram

1. i
2. r
3. lateral shift

K · 3

Each carries 1 mark.

3 Multiple choice

i. **b.** slows down and bends toward the normal — U · 1

Glass is optically denser than air: light slows down in it and bends toward the normal, so $r < i$.

ii. **c.** totally reflected back into the glass — A · 1

50° is more than the critical angle and the light is going from a denser into a rarer medium, so both conditions for total internal reflection are met.

iii. **b.** $\mu = \dfrac{1}{\sin c}$ — K · 1

At the critical angle, $\mu \sin c = \sin 90° = 1$, so $\sin c = \dfrac{1}{\mu}$ and $\mu = \dfrac{1}{\sin c}$.

iv. **c.** 1.5 m — A · 1

Apparent depth = real depth ÷ μ = 2 ÷ (4/3) = 1.5 m. Multiplying by μ instead gives 2.67 m, and 0.67 m is 2 ÷ 3, a slip with the fraction.

v. **b.** repeated total internal reflection at the edge of their core — K · 1

Light inside the core meets its edge at more than the critical angle and is totally reflected, again and again, so it follows the fiber. There is no silver: the cladding of slightly lower refractive index is what makes it work.

4 Very short answers

a. MARKING SCHEME — U · 1

✓ 60° (measured from the normal).

b. MARKING SCHEME — U · 1

✓ Kerosene (light travels more slowly in it).

c. MARKING SCHEME — K · 1

✓ 24.4°.

d. MARKING SCHEME — U · 1

✓ The light is going into a faster (optically rarer) medium.

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5 Short answers

a. MARKING SCHEME U · 2

- ✓ Light from the bottom bends away from the normal as it passes from water into air.
- ✓ The eye traces it back in a straight line and sees the bottom higher than it is.

b. MARKING SCHEME U · 2

- ✓ Diamond's critical angle is only 24.4°, against glass's 41.8°.
- ✓ So light in a diamond is totally reflected again and again and comes back out of the top; in glass more leaks out at the back.

c. MARKING SCHEME U · 2

- ✓ Total internal reflection needs light going from a denser into a rarer medium; air is rarer than water.
- ✓ Going into water, the light bends toward the normal, so the angle of refraction never reaches 90°.

d. MARKING SCHEME K · 2

- ✓ A prism reflects all the light (total internal reflection), while a mirror absorbs some.
- ✓ A prism never tarnishes.

6 Long answers

a. ANSWER U · 4

Let light pass from a medium of refractive index μ into air (refractive index 1). By Snell's law, $\mu \sin i = 1 \times \sin r$. At the critical angle, $i = c$ and $r = 90°$, and $\sin 90° = 1$:

$$\mu \sin c = 1 \qquad \text{so} \qquad \sin c = \frac{1}{\mu} \qquad \text{or} \qquad \mu = \frac{1}{\sin c}$$

So the higher the refractive index, the smaller the critical angle. For example, diamond ($\mu = 2.42$) has $c = 24.4°$, glass ($\mu = 1.5$) has 41.8°.

MARKING SCHEME

- ✓ By Snell's law, $\mu \sin i = 1 \times \sin r$ for light going from the medium into air.
- ✓ At the critical angle, i = c and r = 90°.
- ✓ $\sin 90° = 1$, so $\mu \sin c = 1$.
- ✓ $\sin c = 1/\mu$, or $\mu = 1/\sin c$.

b. ANSWER U · 4

Let O be the object at the bottom and A the point on the surface straight above it. A ray along OA goes straight up. A ray along OB meets the surface at B at angle of incidence i, and leaves bent away from the normal at angle r; traced back, it meets OA at I, the image. Then AO is the real depth and AI the apparent depth.

The angle AOB = i and the angle AIB = r. From the triangles OAB and IAB, $\tan i = \frac{AB}{AO}$ and $\tan r = \frac{AB}{AI}$.

For light going from water into air, $\mu = \frac{\sin r}{\sin i}$. Looking straight down, the angles are very small, so $\sin i \approx \tan i$ and $\sin r \approx \tan r$. Therefore

$$\mu = \frac{\tan r}{\tan i} = \frac{AB/AI}{AB/AO} = \frac{AO}{AI} = \frac{\text{real depth}}{\text{apparent depth}}$$

MARKING SCHEME

- ✓ The diagram or description: a ray along OA, a ray OB bent at B, traced back to I on OA; AO real depth and AI apparent depth.
- ✓ tan i = AB/AO and tan r = AB/AI.
- ✓ μ = sin r/sin i, and looking straight down the angles are very small, so sine ≈ tangent.
- ✓ μ = (AB/AI) ÷ (AB/AO) = AO/AI = real depth ÷ apparent depth.

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7 Numerical problems

a. ANSWER A · 2

$$\mu = \frac{\sin 45^\circ}{\sin 28^\circ} = \frac{0.707}{0.469} = 1.51$$

The refractive index is about 1.51.

MARKING SCHEME

✓ $\mu = \sin 45^\circ \div \sin 28^\circ = 0.707 \div 0.469$.

✓ $\mu \approx 1.51$.

b. ANSWER A · 3

$$\mu = \frac{3 \times 10^8}{2.25 \times 10^8} = 1.33$$

$$\sin c = \frac{1}{1.33} = 0.75 \qquad c = \sin^{-1}(0.75) = 48.6^\circ$$

μ = 1.33 and the critical angle is 48.6°. (The liquid is probably water.)

MARKING SCHEME

✓ $\mu = 3 \times 10^8 \div 2.25 \times 10^8 = 1.33$.

✓ $\sin c = 1 \div 1.33 = 0.75$.

✓ $c = 48.6^\circ$.

c. ANSWER A · 2

Apparent depth = 3.6 − 1.2 = 2.4 cm.

$$\mu = \frac{3.6}{2.4} = 1.5$$

μ = 1.5.

MARKING SCHEME

✓ Apparent depth = 3.6 − 1.2 = 2.4 cm.

✓ $\mu = 3.6 \div 2.4 = 1.5$.

d. ANSWER A · 3

Real depth = 4.90 − 1.12 = 3.78 cm; apparent depth = 4.90 − 2.08 = 2.82 cm.

$$\mu = \frac{3.78}{2.82} = 1.34$$

The refractive index is about 1.34 (it could be water).

MARKING SCHEME

✓ Real depth = 4.90 − 1.12 = 3.78 cm.

✓ Apparent depth = 4.90 − 2.08 = 2.82 cm.

✓ $\mu = 3.78 \div 2.82 \approx 1.34$.

8 Think

ANSWER HA · 3

The farther light meets the surface from the point straight above the lamp, the larger its angle of incidence. Up to the critical angle, 48.8°, it gets out; beyond that, it is totally reflected back into the pool. So light escapes only through a circle.

R = 2 × tan 48.8° = 2 × 1.14 = **2.28 m**, about 2.3 m.

MARKING SCHEME

✓ The angle of incidence grows with distance from the point above the lamp.

✓ Beyond the critical angle, 48.8°, light is totally reflected, so it gets out only inside a circle.

✓ R = 2 × 1.14 ≈ 2.3 m.

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9 Activity: Find the refractive index of glass (Practical 25)

(not marked)

WHAT STUDENTS SHOULD FIND

For ordinary glass, r is about 19.5°, 25.5°, 30.5° and 35.5°, and the ratio stays nearly the same, about 1.5. It wobbles a little because an angle can only be read to about half a degree. The emergent ray is parallel to the incident ray, shifted sideways.

See it at Science Playground

Exhibits and plants at the center, Bhaktapur, that go with this unit. Book a class visit at science-playground.com/booking.

- **Rays of Light** (exhibit): Slant the block in a beam and check the angle scale: the beam bends toward the normal going in, and away from it coming out.
- **The Water Bowl Magnifier** (exhibit): Look at the pebbles through the curved bowl of water: light bends at each surface, and the pebbles look bigger or out of shape.
- **Total Internal Reflection** (exhibit): Inside each fiber, light meets the wall at more than the critical angle and is totally reflected, so it escapes only at the tip.
- **The Ecosystem Pond** (exhibit): Look down at the pebbles on the pond's bottom: they seem nearer the surface than they really are. That is apparent depth.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	11	18	12	3	**44**

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