Unit 10 · Nature and Propagation of Light

HARDER PRACTICE QUESTIONS · ANSWER KEY

Full marks 28

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

The wavelength doesn't stay the same: the **frequency** does, since it is set by the source. $f = c/\lambda = 3.0 \times 10^8/600 \times 10^{-9} = \mathbf{5.0 \times 10^{14}}$ **Hz**, in air and in the plastic alike; it is the wavelength that shrinks, to $600/1.4 = 429$ nm.

MARKING SCHEME

- ✓ The mistake: the wavelength kept at 600 nm in the plastic.
- ✓ The frequency stays 5.0×10^{14} Hz.
- ✓ The wavelength in the plastic is 429 nm.

2 Show that

ANSWER A · 2

The frequency is set by the source and doesn't change at the boundary: each wave that arrives must go on. So $\lambda = \frac{v}{f} = \frac{c/\mu}{f} = \frac{c/f}{\mu} = \frac{\lambda_0}{\mu}$.

MARKING SCHEME

- ✓ The frequency stays the same.
- ✓ $\lambda = v/f = (c/\mu)/f = \lambda_0/\mu$.

3 Predict, then explain

ANSWER HA · 3

Prediction: **away from the normal**.

Light is faster in water (c/1.33) than in glass (c/1.5). The end of the wavefront that enters the water first speeds up, so its wavelet grows faster than the other end moves, and the front swings away from the normal.

$\mu_1 \sin i = \mu_2 \sin r$: $1.5 \sin 40^\circ = 1.33 \sin r$, $\sin r = 0.725$, $\mathbf{r = 46.5^\circ}$.

MARKING SCHEME

- ✓ Away from the normal.
- ✓ Light is faster in water, so the front swings away.
- ✓ $r = 46.5^\circ$.

4 Read the data

ANSWER A · 3

i. $v = 1.50/t$ and $\mu = c/v = ct/1.50$: water $3.0 \times 10^8 \times 6.65 \times 10^{-9}/1.50 =$ **1.33**, ethanol **1.36**, glycerol **1.47**.

ii. Light would take $1.50/c = 5.0$ ns in air: it is **slower** in every liquid, the more so the higher the refractive index. This supports the **wave theory**: Newton's theory says it would be faster.

MARKING SCHEME

- ✓ $\mu = ct/1.50$.
- ✓ 1.33, 1.36 and 1.47.
- ✓ Slower than in air, so the wave theory.

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5 A real setting

ANSWER A · 3

$\sin C = 1.46/1.48 = 0.986$, so $\mathbf{C = 80.6^\circ}$: light meeting the boundary at more than 80.6° from the normal is totally reflected.

$v = c/1.48 = 2.03 \times 10^8$ m/s; $t = 10\,000/2.03 \times 10^8 = \mathbf{4.9 \times 10^{-5}\ s}$ (49 μs).

MARKING SCHEME

- ✓ $\sin C = 1.46/1.48$.
- ✓ $C = 80.6^\circ$.
- ✓ $t = 49\ \mu s$.

6 Which explanation fits?

ANSWER HA · 3

Newton: the corpuscles speed up, $v = \mu c = 1.44 \times 3.0 \times 10^8 = \mathbf{4.3 \times 10^8\ m/s}$. Huygens: $v = c/\mu = \mathbf{2.1 \times 10^8\ m/s}$.

Light is slower in water, as in every such liquid, so **Huygens' wave explanation** fits and Newton's doesn't.

MARKING SCHEME

- ✓ Newton's prediction 4.3×10^8 m/s.
- ✓ Huygens' prediction 2.1×10^8 m/s.
- ✓ Slower in the liquid: the wave theory fits.

7 Estimate it

ANSWER HA · 3

$d^2/(8R) = 0.10^2/(8 \times 1.5 \times 10^{11}) \approx \mathbf{8 \times 10^{-15}\ m}$, about **a hundred-millionth of a wavelength**. The wavefront is flat to far better than a wavelength across the lens, so it is right to treat sunlight as plane waves.

MARKING SCHEME

- ✓ About 8×10^{-15} m.
- ✓ Far smaller than 500 nm.
- ✓ So sunlight's wavefronts are practically plane.

8 Correct the misconceptions

ANSWER U · 3

1. The frequency doesn't change at a boundary; the **speed** falls, and so the wavelength gets shorter ($\lambda = v/f$).
2. Rays are **perpendicular** to the wavefronts, not parallel.
3. A wavefront joins the points that are **in the same phase**. In a uniform medium they are the same distance from a point source, but not when the light has crossed media at different speeds.

MARKING SCHEME

- ✓ The frequency stays; the speed falls.
- ✓ Rays are perpendicular to wavefronts.
- ✓ A wavefront joins points in the same phase.

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9 Think

ANSWER HA · 3

While the far end B of the front travels BB′ = vt in the glass, the wavelet from A grows AA′ = ct in the air, 1.5 times as much. For a refracted front there must be a tangent from B′ to that wavelet, so AA′ must be less than AB′: sin r = AA′/AB′ = 1.5 × sin 50° = 1.15, which is impossible. The wavelet in the air is already wider than AB′, no tangent can be drawn, and all the light is reflected: **total internal reflection** (since sin 50° = 0.77 > v/c = 0.67).

MARKING SCHEME

- ✓ The wavelet in air grows faster: AA′ = ct, BB′ = vt.
- ✓ sin r would be 1.15, more than 1: no tangent from B′.
- ✓ So no refracted front: total internal reflection.

10 Make your own

ANSWER HA · 2

sin i = μ sin 30° = μ/2. For example, **μ = 1.4 and i = 44.4°** (sin i = 0.70). Any μ with μ/2 at most 1.

MARKING SCHEME

- ✓ sin i = μ sin 30°.
- ✓ A suitable pair, e.g. μ = 1.4 and i = 44.4°.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	6	8	14	**28**

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