Unit 16 · Refraction through Prisms

HARDER PRACTICE QUESTIONS · ANSWER KEY

Full marks 30

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 angles must be **halved** before the sine is taken: $\mu = \sin((A + \delta_m)/2) \div \sin(A/2) = \sin 51° \div \sin 30°$ $= 0.777 \div 0.5 = \mathbf{1.55}$. Her value should have warned her: no glass has a refractive index as low as 1.13. (The halves come from $i = (A + \delta_m)/2$ and $r = A/2$ at minimum deviation.)

MARKING SCHEME

- ✓ The mistake: the angles $(A + \delta_m)$ and A must be halved.
- ✓ $\mu = \sin 51° \div \sin 30°$.
- ✓ $\mu = 1.55$.

2 Reading a graph

ANSWER HA · 4

(The readings are made up, from a prism with μ about 1.5.)

i. $\delta_m \approx \mathbf{37}°$, so $\mu = \sin((60° + 37°)/2) \div \sin 30° = \sin 48.5° \div 0.5 = \mathbf{1.50}$.

ii. $e = \delta + A - i = 38.5° + 60° - 40° = \mathbf{58.5}°$.

iii. Reversed, the ray goes in at 58.5° and comes out at 40°, turned by the same 38.5°. Her table agrees: between 55° (38.0°) and 60° (39.0°) the deviation passes 38.5°.

iv. Near the minimum the deviation changes very little, by about half a degree over 10° of incidence, so small errors in measuring δ hide where the lowest point is (though δ_m itself is well known).

MARKING SCHEME

- ✓ $\delta_m \approx 37°$ and $\mu \approx 1.50$.
- ✓ $e = 58.5°$.
- ✓ About 58.5° gives the same deviation (reversibility); the table agrees.
- ✓ The curve is flat near the minimum, so its position is uncertain.

3 Least and most

ANSWER HA · 4

The critical angle is $C = \sin^{-1}(1/1.5) = 41.8°$. Light just comes out (grazing the second face) when $r_2 = C = 41.8°$. Then $r_1 = A - r_2 = 60° - 41.8° = 18.2°$, and $\sin i = 1.5 \sin 18.2° = 1.5 \times 0.312 = 0.468$, so $i = \mathbf{27.9}°$.

For a smaller i, r_1 is smaller, so $r_2 = 60° - r_1$ is more than 41.8°: the light is **totally reflected** at the second face and doesn't come out there.

MARKING SCHEME

- ✓ $C = 41.8°$, and light just emerges when $r_2 = C$.
- ✓ $r_1 = 60° - 41.8° = 18.2°$.
- ✓ $i = 27.9°$.
- ✓ For smaller i, $r_2 > C$: total internal reflection at the second face.

4 A real setting

ANSWER A · 3

3 prism diopters turn light by 3 cm in 100 cm: $\delta = \tan^{-1}(3/100) = \mathbf{1.72}°$.

For a thin prism $\delta = (\mu - 1)A$, so $A = 1.72° \div 0.52 = \mathbf{3.3}°$.

MARKING SCHEME

- ✓ $\delta = \tan^{-1}(0.03) = 1.72°$ (or $3 \times 0.57°$).
- ✓ $A = \delta/(\mu - 1)$.
- ✓ $A = 3.3°$.

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5 Design it

ANSWER A · 3

The crown prism turns light by $(1.52 - 1) \times 5^\circ = 2.6^\circ$ towards its base. The flint prism, turned the other way, must turn it back by 2.6°: $(1.62 - 1)A = 2.6^\circ$, so $A = 2.6^\circ \div 0.62 = \mathbf{4.2}^\circ$.

MARKING SCHEME

- ✓ Deviation of the crown prism 2.6°.
- ✓ The two deviations must be equal and opposite: $0.62A = 2.6^\circ$.
- ✓ $A = 4.2^\circ$.

6 Predict, then explain

ANSWER HA · 3

Towards the refracting edge. The thin glass walls only shift the light a little, so what matters is the air inside. Air is optically rarer than the water around it, so at the first face the ray bends away from the normal and at the second towards it: every bend is the opposite of what happens in a glass prism in air. A glass prism in air turns light towards its base, so this one turns it the other way.

MARKING SCHEME

- ✓ Towards the refracting edge (away from the base).
- ✓ The prism's material (air) is rarer than its surroundings (water), so the bends are opposite to those in a glass prism in air.
- ✓ So the deviation is reversed.

7 What if?

MARKING SCHEME A · 3

- ✓ Larger μ: more deviation.
- ✓ In water: μ relative to water is smaller, so less deviation.
- ✓ Violet: larger μ, more deviation.

8 Correct the misconceptions

ANSWER U · 3

1. The deviation is **least** (minimum deviation), not greatest, when the ray passes symmetrically.
2. There the angle of incidence equals the angle of **emergence** (and $r_1 = r_2 = A/2$), not the angle of the prism.
3. A thin prism deviates every ray falling nearly normally by the **same** angle, $(\mu - 1)A$, whatever its angle of incidence.

MARKING SCHEME

- ✓ The symmetrical path gives the minimum deviation.
- ✓ There $i = e$ ($r_1 = r_2 = A/2$), not $i = A$.
- ✓ A thin prism's deviation $(\mu - 1)A$ doesn't depend on the angle of incidence (for small angles).

9 Think

ANSWER HA · 2

$\mu = \sin((A + \delta_m)/2) \div \sin(A/2)$: with the same A, a larger δ_m gives a larger sine on top (the half-angle stays below 90°), so **Q** has the larger refractive index. Since $\sin C = 1/\mu$, a larger μ means a smaller critical angle: **Q** again.

MARKING SCHEME

- ✓ Q has the larger μ: same A, larger δ_m gives a larger $\sin((A + \delta_m)/2)$.
- ✓ Q has the smaller critical angle, since $\sin C = 1/\mu$.

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10 Make your own

HA · 2

ANSWER

For example: “What must the refracting angle of a prism of refractive index 1.5 be, for a ray falling on it at 45° to pass at minimum deviation?” $\sin r = \sin 45° \div 1.5 = 0.471$, $r = 28.1°$, and at minimum deviation $A = 2r = 56.3°$. Any correct problem with this answer is right.

MARKING SCHEME

- ✓ A sensible problem whose answer is $A = 56.3°$.
- ✓ Solved correctly.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	6	9	15	**30**

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