Unit 16 · Refraction through Prisms

ANSWER KEY · FOR TEACHERS

Full marks 37

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. refracting faces
2. base
3. refracting angle
4. principal section
5. emergence
6. deviation
7. minimum deviation
8. thin prism

K · 4

Each carries 0.5 mark.

2 Label the diagram

1. refracting edge
2. A
3. base
4. refracting face

K · 2

Each carries 0.5 mark.

3 Multiple choice

i. **b.** $r_1 + r_2 = A$ — K · 1

From the four-sided figure made by the two faces and the two normals, $r_1 + r_2 = A$, for every ray.

ii. **a.** 20° — A · 1

$\delta = i + e - A = 45^\circ + 35^\circ - 60^\circ = 20^\circ$.

iii. **b.** 30° — U · 1

At minimum deviation $r_1 = r_2 = A/2 = 30^\circ$.

iv. **c.** 3° — A · 1

$\delta = (\mu - 1)A = 0.6 \times 5^\circ = 3^\circ$.

v. **b.** towards its base — U · 1

The two faces lean towards each other, so the second bend never undoes the first: the light is always turned towards the base.

4 Very short answers

a. MARKING SCHEME — K · 1

✓ The angle between the incident ray (produced) and the emergent ray.

b. MARKING SCHEME — K · 1

✓ $\delta = (\mu - 1)A$.

c. MARKING SCHEME — U · 1

✓ Near the minimum the deviation hardly changes with the angle of incidence, so δ_m is easy to find exactly.

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5 Short answers

a. MARKING SCHEME U · 2

- ✓ In the four-sided figure made by the two faces and the two normals, the angles at the faces are 90° each, so A + ∠QNR = 180°.
- ✓ In the triangle made by the ray inside and the two normals, $r_1 + r_2 + \angle QNR = 180°$; so $r_1 + r_2 = A$.

b. MARKING SCHEME U · 2

- ✓ A ray entering at i and leaving at e can be reversed: entering at e it leaves at i, with the same deviation.
- ✓ If $i \neq e$, the least deviation would happen at two angles of incidence; the graph has only one lowest point, so i = e.

c. MARKING SCHEME K · 2

- ✓ Any one, e.g. prism glasses for an eye that turns slightly (so both eyes see one image).
- ✓ Any second, e.g. steering a laser beam (a Risley pair), making a laser diode's spot round, aligning optical parts, or an achromatic prism.

6 Long answer

ANSWER U · 4

For any ray, $r_1 + r_2 = A$ and $\delta = i + e - A$. At minimum deviation the ray passes symmetrically: i = e and $r_1 = r_2 = r$. Then 2r = A, so r = A/2; and $\delta_m = 2i - A$, so $i = (A + \delta_m)/2$. By Snell's law at the first face, $\mu = \sin i \div \sin r = \sin((A + \delta_m)/2) \div \sin(A/2)$.

MARKING SCHEME

- ✓ $r_1 + r_2 = A$ and $\delta = i + e - A$.
- ✓ At minimum deviation i = e and $r_1 = r_2$, so r = A/2.
- ✓ $i = (A + \delta_m)/2$.
- ✓ $\mu = \sin i/\sin r = \sin((A + \delta_m)/2)/\sin(A/2)$.

7 Numerical problems

a. ANSWER A · 3

$\sin r_1 = \sin 55° \div 1.52 = 0.819 \div 1.52 = 0.539$, $r_1 = 32.6°$. $r_2 = A - r_1 = 60° - 32.6° = 27.4°$.
$\sin e = 1.52 \sin 27.4° = 1.52 \times 0.460 = 0.699$, so e = **44.4**°.
$\delta = i + e - A = 55° + 44.4° - 60° =$ **39.4**°.

MARKING SCHEME

- ✓ $r_1 = 32.6°$ and $r_2 = 27.4°$.
- ✓ e = 44.4°.
- ✓ $\delta = 39.4°$.

b. ANSWER A · 3

$\mu = \sin((60° + 39.0°)/2) \div \sin 30° = \sin 49.5° \div 0.5 = 0.760 \div 0.5 =$ **1.52**.
At minimum deviation $i = (A + \delta_m)/2 =$ **49.5**°.

MARKING SCHEME

- ✓ The formula with A = 60° and $\delta_m = 39.0°$ put in.
- ✓ $\mu = 1.52$.
- ✓ i = 49.5°.

c. ANSWER A · 4

i. $\sin((45° + \delta_m)/2) = 1.6 \sin 22.5° = 1.6 \times 0.383 = 0.612$, so $(45° + \delta_m)/2 = 37.8°$ and $\delta_m =$ **30.5**°.

ii. At normal incidence $r_1 = 0$, so $r_2 = A = 45°$. The critical angle is $\sin^{-1}(1/1.6) = 38.7°$. 45° is more than 38.7°, so the ray is **totally reflected** at the second face and does not come out.

MARKING SCHEME

- ✓ $\sin((A + \delta_m)/2) = \mu \sin(A/2) = 0.612$.
- ✓ $\delta_m = 30.5°$.
- ✓ $r_2 = A = 45°$ for normal incidence.
- ✓ $C = 38.7° < 45°$, so total internal reflection: no emergent ray.

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8 Think

ANSWER HA · 3

At each face the light bends: towards the normal going in and away from it coming out. In a slab the two normals are parallel, so the second bend is exactly opposite to the first and undoes it: the ray only shifts sideways. In a prism the faces lean towards each other, so the normals are not parallel and the second bend adds to the first instead of undoing it. The ray is turned overall towards the base.

MARKING SCHEME

- ✓ In a slab the faces (and normals) are parallel, so the bend going out undoes the bend going in: only a sideways shift.
- ✓ In a prism the faces are inclined, so the two bends don't cancel (they add).
- ✓ The prism turns light towards its base.

9 Activity: The deviation produced by a prism (Activity 16.1)

(not marked)

WHAT STUDENTS SHOULD FIND

For a 60° glass prism ($\mu \approx 1.5$) the deviation is about 47° at 30°, falls to a least value of about 37° near i = 48°–49°, and rises again to about 39° at 60°. At the lowest point i and e are equal (within a degree or two), and the ray inside runs parallel to the base. With $\delta_m \approx 37°$, $\mu = \sin 48.5° \div \sin 30° \approx 1.5$.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	11	11	12	3	**37**

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