



Unit 10 • Wave: refraction and total internal reflection

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. refraction
2. optically denser
3. refractive index
4. Snell's law
5. apparent depth
6. critical angle
7. total internal reflection
8. cladding

K • 4

Each carries 0.5 mark.

2 Label the diagram

- | | | |
|------|---------------------|-------|
| 1. N | 4. air | K • 3 |
| 2. i | 5. glass slab | |
| 3. e | 6. lateral shift CD | |

Each carries 0.5 mark.

3 Multiple choice

- i. **d.** The angle of refraction is greater than the angle of incidence when light travels from a denser medium into a rarer medium. U • 1
- Going into a rarer (faster) medium, light bends away from the normal, so $r > i$. Light bends both ways in and out, not only into a denser medium; it bends **away** from the normal going into a rarer medium; and going into a denser medium, i is **bigger** than r .
- ii. **d.** Medium 1 is denser and medium 2 is rarer. A • 1
- The light bends away from the normal ($30^\circ > 15^\circ$), so it has sped up: medium 2 is rarer. The ratio of speeds is $\sin 30^\circ \div \sin 15^\circ \approx 1.9$, and light is faster in medium 2, not medium 1.
- iii. **d.** $\angle i = \angle e > \angle r$ K • 1
- The angle of emergence equals the angle of incidence, and the angle of refraction inside the glass is smaller than both.
- iv. **a.** 42° K • 1
- $\sin c = 1/1.5$, so $c = 41.8^\circ \approx 42^\circ$. (49° is water's, 24° diamond's, 47° alcohol's.)
- v. **d.** a pencil looking bent in water U • 1
- The bent pencil is ordinary refraction: light leaving the water bends away from the normal, but gets out. In the other three, light meets a boundary from the denser side at more than the critical angle and is turned back.

4 Very short answers

- a. MARKING SCHEME K • 1
✓ No unit, because it is a ratio of two speeds.
- b. MARKING SCHEME K • 1
✓ The change in the speed of light from one medium to the other.
- c. MARKING SCHEME U • 1
✓ Away from the normal.



- d. MARKING SCHEME
✓ Endoscope.

K · 1

5 Short answers

- a. MARKING SCHEME

U · 2

- ✓ Light from a star passes through layers of air whose refractive index keeps changing as the air moves, so it is refracted by changing amounts.
- ✓ A star is so far away that it is a point of light, so its brightness and position flicker: it twinkles.

- b. MARKING SCHEME

K · 2

- ✓ Light must travel from a denser medium into a rarer medium.
- ✓ The angle of incidence must be greater than the critical angle.

6 Long answer

ANSWER

A · 4

- i. 30° is less than the critical angle, so most of the light is refracted out into the air, bent away from the normal (at about 49°); a little is reflected.
- ii. At the critical angle, the refracted ray just skims along the surface: the angle of refraction is 90° .
- iii. 60° is greater than the critical angle, so no light gets out: all of it is reflected back into the glass (total internal reflection).
- iv. An optical fiber (also: an endoscope, a prism periscope, binoculars).

MARKING SCHEME

- ✓ i. Refracted out into the air, bent away from the normal.
- ✓ ii. The refracted ray grazes along the surface (angle of refraction 90°).
- ✓ iii. Totally reflected back into the glass (total internal reflection).
- ✓ iv. Any one device: optical fiber, endoscope, prism periscope, binoculars.

7 Numerical problems

- a. ANSWER

A · 2

$$\mu = \sin i \div \sin r = \sin 45^\circ \div \sin 33^\circ = 0.7071 \div 0.5446 = 1.30.$$

MARKING SCHEME

- ✓ $\mu = \sin i \div \sin r = \sin 45^\circ \div \sin 33^\circ = 0.7071 \div 0.5446$.
- ✓ $\mu = 1.30$.

- b. ANSWER

A · 4

- i. $v = c \div \mu = 3 \times 10^8 \div 1.47 = 2.04 \times 10^8 \text{ m/s}$.
- ii. $\sin c = 1 \div \mu = 1 \div 1.47 = 0.680$, so $c = \sin^{-1}(0.680) \approx 43^\circ$.

MARKING SCHEME

- ✓ $v = c \div \mu = 3 \times 10^8 \div 1.47$.
- ✓ $v = 2.04 \times 10^8 \text{ m/s}$.
- ✓ $\sin c = 1 \div \mu = 1 \div 1.47 = 0.680$.
- ✓ $c \approx 43^\circ (42.8^\circ)$.

8 Think

ANSWER

HA · 2

Kerosene is optically denser, because light is slower in it. But it floats, so its ordinary density is less than water's (about 0.8 g/cm^3 against 1 g/cm^3). Optical density is about how much a material slows light, not about its mass per volume.

MARKING SCHEME

- ✓ Kerosene is optically denser, because light travels more slowly in it.
- ✓ No: kerosene floats, so its ordinary density is less than water's; optical density depends on the speed of light, not on mass per volume.



9 Activity: The coin that comes back

(not marked)

WHAT STUDENTS SHOULD FIND

In the empty cup the rim hides the coin. As the water rises, the coin comes back into view and seems to float up: its light bends away from the normal as it leaves the water, clears the rim and reaches the eye, which sees the coin higher than it is. The pencil looks bent at the surface for the same reason, and the bucket looks shallower than it is (apparent depth less than real depth).

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): Put the glass block in the laser beams and watch them bend as they enter and leave it.
- **Total Internal Reflection** (exhibit): Steepen the beam until it can't escape and bounces back inside: total internal reflection.
- **The Periscope** (exhibit): This periscope turns light with two 45° mirrors; the book's prisms do it without mirrors.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	14	5	11	2	32





Unit 10 • Wave: dispersion, lenses and power

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. dispersion
2. spectrum
3. violet
4. convex lens
5. principal focus
6. optical center
7. power
8. diopters

K • 4

Each carries 0.5 mark.

2 Label the diagram

- | | |
|-----------------|--------------------|
| 1. biconvex | 4. plano-concave |
| 2. biconcave | 5. concavo-convex |
| 3. plano-convex | 6. convexo-concave |

K • 3

Each carries 0.5 mark.

3 Multiple choice

- i. d. violet

K • 1

Violet has the shortest wavelength, travels slowest in glass, and so is bent the most. Red is fastest and bent the least, which is why red is at the top of the spectrum from a prism with its base down.

- ii. a. virtual, erect, magnified

U • 1

An object between F and O of a convex lens: the lens works as a magnifying glass, giving a virtual, erect (upright), magnified image on the same side as the object.

- iii. b. A concave lens forms a virtual, erect and diminished image of an object.

U • 1

A concave lens always does, wherever the object is. A convex lens's image depends on where the object is (it can be diminished, the same size or magnified, and real or virtual), so the first and third statements are only sometimes true.

- iv. c. A is concave with $f = -50$ cm, and B is convex with $f = +20$ cm

A • 1

$f = 1/P$: for A, $1/(-2) = -0.5$ m (concave); for B, $1/5 = +0.2$ m (convex). A negative power always means a concave, diverging lens.

- v. b. behind you, low in the west

A • 1

A rainbow is always on the side of the sky opposite the Sun, centered on the point directly opposite it. In the evening the Sun is low in the west, so the rainbow is in the east, and you face away from the Sun to see it.

4 Very short answers

- a. MARKING SCHEME

K • 1

✓ Diopter (D).

- b. MARKING SCHEME

U • 1

✓ At $2F_1$ (twice the focal length from the lens).



- c. MARKING SCHEME A • 1
 ✓ $f = 1 \div 2 = 0.5 \text{ m (50 cm)}$.

5 Short answers

- a. MARKING SCHEME U • 2
 ✓ In glass the speed of light depends on its color (wavelength): red travels fastest and violet slowest, so the refractive index is different for each color.
 ✓ So each color is bent by a different amount (violet most, red least), and the colors separate.
- b. MARKING SCHEME U • 2
 ✓ Any one difference, e.g. a convex lens is thicker in the middle and converges light; a concave lens is thinner in the middle and diverges light.
 ✓ Any second difference, e.g. positive against negative focal length and power, or real and virtual images against only virtual, erect, diminished ones.
- c. MARKING SCHEME A • 2
 ✓ X is violet and Y is red.
 ✓ Red travels faster in glass than violet (glass has a smaller refractive index for red), so red is bent less at each face.

6 Long answer

ANSWER

U • 4

A rainbow is seen when the Sun is behind the observer and drops of water are in the air in front. Sunlight entering a drop is refracted and dispersed, reflected from the back of the drop, and refracted again as it comes out. Red leaves at about 42° to the sunlight and violet at about 40° . So the eye gets red light only from drops lying at 42° from the line through the Sun and the observer's head: these drops lie on a circle around that line, so the bow is always the same size, with red outside. The ground hides the lower part of the circle, so we see an arc (exactly a semicircle when the Sun is on the horizon).

MARKING SCHEME

- ✓ The Sun is behind the observer, and drops of water are in the air in front (after rain).
- ✓ Sunlight is refracted and dispersed as it enters each drop, reflected from the back of the drop, and refracted again as it comes out.
- ✓ Each color leaves at its own angle: red at about 42° and violet at about 40° to the sunlight, so red is on the outside of the bow.
- ✓ The drops that send one color to the eye lie on a circle around the line from the Sun through the observer's head, so the bow is always the same size; the ground hides the lower part, so we see an arc.

7 Numerical problems

- a. ANSWER A • 2
 $f = 1 \div P = 1 \div (-6 \text{ D}) = -0.1667 \text{ m} = -16.67 \text{ cm}$. The minus sign shows it is a concave lens.
- MARKING SCHEME
 ✓ $f = 1 \div P = 1 \div (-6) = -0.1667 \text{ m (-16.67 cm)}$.
 ✓ A concave (diverging) lens, because the power and focal length are negative.



b. ANSWER

A • 4

- i. The +4 D lens is thicker: a greater power means a shorter focal length, which needs more strongly curved surfaces.
- ii. For +2 D: $f = 1 \div 2 = 0.5 \text{ m} = 50 \text{ cm}$. For +4 D: $f = 1 \div 4 = 0.25 \text{ m} = 25 \text{ cm}$.

MARKING SCHEME

- ✓ The +4 D lens is thicker.
- ✓ Greater power means a shorter focal length, so its surfaces are more strongly curved.
- ✓ For +2 D: $f = 1 \div 2 = 0.5 \text{ m} = 50 \text{ cm}$.
- ✓ For +4 D: $f = 1 \div 4 = 0.25 \text{ m} = 25 \text{ cm}$.

8 Think**ANSWER**

HA • 2

The two faces of a slab are parallel, so the second face bends each color back by exactly as much as the first face bent it. The colors come out parallel and on top of one another, and mix into white again. A prism's faces are at an angle, so its second bend adds to the first and the colors spread out.

MARKING SCHEME

- ✓ The second (parallel) face bends each color back by the same amount as the first face bent it.
- ✓ So the colors come out parallel and overlapping, and look white; in a prism the faces are at an angle, so the second bend adds to the first.

9 Activity: White light into colors, and back

(not marked)

WHAT STUDENTS SHOULD FIND

The prism makes a band of colors on the wall, red at one end and violet at the other: white light is dispersed, because each color is bent by a different amount. The disc spun slowly shows its seven colors; spun fast it looks whitish, because the eye receives all the colors one after another faster than it can tell them apart. The mist shows a small rainbow, about 42° from the shadow of the head, made by the drops dispersing sunlight.

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.

- **The Spectroscope** (exhibit): Look at a lamp through the tube: its "white" light spreads into a band of colors.
- **String Prism** (exhibit): The strings show white light fanning into colors, red bent least and violet most.
- **The Fresnel Lens** (exhibit): This flat sheet magnifies like a thick lens: it keeps only the curved surfaces, in rings.
- **The Water Bowl Magnifier** (exhibit): Look through the round bowl of water: it bends light like a convex lens.
- **The Single Lens Camera** (exhibit): Look inside the box: the lens throws an upside-down real image of the world on a screen.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	9	11	11	2	33





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. accommodation
2. ciliary muscles
3. near point
4. short-sightedness
5. concave lens
6. cataract
7. cone cells
8. vitamin A

K • 4

Each carries 0.5 mark.

2 Label the diagram

1. ciliary muscle
2. cornea
3. pupil (a hole)
4. iris (colored)
5. suspensory ligaments

6. vitreous humor (clear jelly)
7. lens
8. retina
9. blind spot
10. optic nerve

K • 5

Each carries 0.5 mark.

3 Multiple choice

- i. a. about 25 cm

K • 1

A normal adult eye sees clearly from about 25 cm (the least distance of distinct vision) to infinity, its far point. 2 cm is about the depth of the eyeball.

- ii. b. the cornea

U • 1

The cornea does about two-thirds of the focusing, because light bends most where it goes from air into the eye. The lens does the rest, and its special job is to adjust the focus. The pupil is just a hole; the retina is where the image forms.

- iii. c. When the shape of the surface of the cornea changes, a defect of vision is seen.

U • 1

The cornea does most of the eye's focusing, so a change in its shape (as in keratoconus, or a too-curved cornea) causes a defect of vision. A cloudy lens is a cataract; a focal length that is too long (a weak lens) goes with long sight; night blindness is a problem of the rod cells.

- iv. b. the ciliary muscles relax and the lens gets thinner, with a longer focal length

A • 1

For distant objects the eye needs a weaker lens, so the ciliary muscles relax and the lens is pulled thin. The retina can't move; that is why the lens must change instead.

- v. a. a concave lens, as she is short-sighted

A • 1

She sees near things but not far ones: short-sightedness (myopia). Distant light is focused in front of her retina, so a concave lens is needed to spread it out a little first.

4 Very short answers

- a. MARKING SCHEME

K • 1

✓ At infinity.

- b. MARKING SCHEME

K • 1

✓ Rhodopsin.



- c. MARKING SCHEME U · 1
✓ There are no rods or cones (light-sensitive cells) at the blind spot.

5 Short answers

- a. MARKING SCHEME U · 2
✓ The rod cells, which let us see in dim light, contain the pigment rhodopsin, made from a protein and vitamin A.
✓ Without enough vitamin A, too little rhodopsin is made, so the rods can't respond to dim light.
- b. MARKING SCHEME U · 2
✓ Any one difference, e.g. the nearest point seen clearly (about 25 cm) against the farthest (infinity).
✓ Any second difference, e.g. ciliary muscles fully contracted and lens thickest, against relaxed and lens thinnest.
- c. MARKING SCHEME A · 2
✓ Looking at the distant object, the ciliary muscles relax and the suspensory ligaments pull the lens thinner.
✓ Its curvature decreases and its focal length increases, so the nearly parallel light from far away is focused on the retina (accommodation).

6 Long answer

ANSWER

A · 4

- Short-sightedness (myopia).
- In front of the retina.
- The eyeball is too long, or the eye lens (or cornea) is too strongly curved, so its focal length is too short.
- A concave lens: it spreads the parallel rays from the board a little before they enter the eye, so they seem to come from the eye's far point and are focused on the retina.

MARKING SCHEME

- ✓ i. Short-sightedness (myopia).
- ✓ ii. In front of the retina.
- ✓ iii. Any two causes: the eyeball is too long; the lens or cornea is too strongly curved (focal length too short).
- ✓ iv. A concave lens, which spreads the rays so they seem to come from the far point and are focused on the retina.

7 Numerical problems

- a. ANSWER A · 2
His far point is 2 m, so he needs a concave lens with $f = -2$ m. $P = 1 \div f = 1 \div (-2 \text{ m}) = -0.5$ D: a concave lens.

MARKING SCHEME

- ✓ $f = -2$ m (the far point, with a minus sign for a concave lens).
- ✓ $P = 1 \div (-2) = -0.5$ D, a concave lens.



b. ANSWER

A • 4

- i. $f = 1 \div P = 1 \div (-2.5 \text{ D}) = -0.4 \text{ m} = -40 \text{ cm}$.
- ii. Concave (the power is negative).
- iii. Short-sightedness (myopia).
- iv. Up to 40 cm, her far point: the lens makes distant objects seem to be at its focal length.

MARKING SCHEME

- ✓ $f = 1 \div (-2.5) = -0.4 \text{ m} (-40 \text{ cm})$.
- ✓ Concave lens.
- ✓ Short-sightedness (myopia).
- ✓ Up to about 40 cm (her far point equals the focal length of the lens).

8 Think**ANSWER**

HA • 2

Generally **yes**. A thicker lens is more strongly curved, so it has a shorter focal length and a greater power. A more serious defect needs a more powerful lens to correct it: a very short-sighted eye needs a strong concave lens (thick at the edges), a very long-sighted eye a strong convex lens (thick in the middle). So thick lenses usually mean a large defect. (One caution: lenses made of high-index glass or plastic bend light more, so they can correct the same defect with a thinner lens. It is the **power**, in diopters, that really measures the defect, not the thickness.)

MARKING SCHEME

- ✓ A thicker lens is more strongly curved, so it has a shorter focal length and a greater power.
- ✓ A bigger defect needs a more powerful lens, so generally **yes**; but it is the power in diopters, not the thickness, that measures the defect (high-index glass gives the same power with a thinner lens).

9 Activity: Your own eyes

(not marked)

WHAT STUDENTS SHOULD FIND

At about 20–30 cm the dot vanishes: its image falls on the blind spot, where there are no rods or cones. The pupils shrink in bright light, because the iris closes them to let in less light; the covered eye's pupil is bigger, as it was in the dark. Looking from the book to the tree, the tree is sharp after a moment: the ciliary muscles relax and the lens becomes thinner (accommodation).

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.

- **Judging Distance** (exhibit): Line up the rods with one eye shut, then with both: two eyes judge distance far better.
- **Color Vision Test** (exhibit): Try the Ishihara plates: the numbers you can or can't see show red–green color blindness.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	12	7	14	2	35

