

Bending light: refraction, critical angle and lenses

Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Worksheet answers

Worked answers follow each problem in the same order. Check every angle against the normal, make sure your calculator is in degree mode, and compare your ray diagrams with the stated image positions.

Level: Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · **Curriculum:** IGCSE 3.2

Problem 1 Law of reflection

1. Angle of reflection = angle of incidence = **35°**.
2. The normal is at 90° to the mirror, so the angle to the surface = $90^\circ - 35^\circ = \mathbf{55^\circ}$.
3. Incident and reflected rays are each 35° from the normal, on opposite sides: $35^\circ + 35^\circ = \mathbf{70^\circ}$.

Problem 2 Bending at a boundary

1. Glass is denser and slows light, so the ray bends **towards the normal**.
2. Leaving the glass, light speeds up again, so it bends **away from the normal**.
3. The effect is **refraction**, caused by the change in the speed of light.

Problem 3 Index of an acrylic block

1. $n = \sin i \div \sin r$.
2. $n = 0.500 \div 0.334 = \mathbf{1.50}$ (no unit).

Problem 4 Light in water

1. $n = 3.00 \times 10^8 \div 2.25 \times 10^8 = \mathbf{1.33}$.
2. It is a ratio of two speeds, so the units cancel.

Problem 5 Three rays at a lens

1. It is refracted so that it passes through the **principal focus** on the far side.
2. It passes straight through **without changing direction**.
3. The focal length is **the distance from the centre of the lens to the principal focus**.

Problem 6 Conditions for total internal reflection

1. The light must travel from a **denser to a less dense** material, and the angle of incidence

must be **greater than the critical angle**.

2. **An optical fibre** (or binoculars prism, or cat's eye reflector).

Problem 7 Finding the refraction angle

1. $\sin r = \sin i \div n$.

2. $\sin r = \sin 50^\circ \div 1.50 = 0.766 \div 1.50 = 0.511$.

3. $r = \sin^{-1}(0.511) = \mathbf{30.7^\circ}$.

Problem 8 Spearfishing angle

1. $\sin r = \sin 60^\circ \div 1.33 = 0.866 \div 1.33 = 0.651$, so $r = \mathbf{40.6^\circ}$.

2. 40.6° is smaller than 60° , so the ray is **closer to the normal**.

Problem 9 Critical angle of perspex

1. $\sin c = 1 \div n$.

2. $\sin c = 1 \div 1.49 = 0.671$, so $c = \mathbf{42.2^\circ}$.

3. 50° is greater than c , so the ray undergoes **total internal reflection**.

Problem 10 Experimental readings

1. $\sin i$: 0.342, 0.643, 0.866, 0.985. $\sin r$: 0.225, 0.423, 0.574, 0.643.

2. $n = 1.52, 1.52, 1.51, 1.53$; mean = **1.52**.

3. Random errors in reading the protractor partly cancel when values are averaged.

Problem 11 Why fibres carry the internet

1. Light hits the glass-air boundary at an angle larger than the critical angle, so it is **totally internally reflected** again and again along the fibre.

2. If the angle of incidence were smaller than the critical angle, part of the light would refract out, so the signal would **leak out and be lost**.

Problem 12 Magnifying a seed

1. $m = 30 \div 12 = \mathbf{2.5}$.

2. image height = $m \times \text{object height} = 2.5 \times 8.0 = \mathbf{20 \text{ mm}}$.

Problem 13 Real image on a screen

1. Draw the parallel ray through the far F and the ray through the centre; they cross at the image tip.

2. The image is **24 cm** from the lens, **6.0 cm** tall ($m = 2$), **real and inverted**. Check: $1/f = 1/u + 1/v$ gives $1/8 = 1/12 + 1/24$.

Problem 14 Camera, projector or magnifier

1. Beyond 2F: real, inverted, smaller. Between F and 2F: real, inverted, larger. Inside F: virtual, upright, larger.
2. **Camera, projector, magnifying glass** respectively.

Problem 15 Spot the error

1. The ray bends **away** from the normal (60° is larger than 40°). Entering glass it should bend towards the normal.
2. $\sin r = \sin 40^\circ \div 1.50 = 0.643 \div 1.50 = 0.429$, so $r = \mathbf{25.4^\circ}$.

Problem 16 Light through a parallel block

1. $\sin r = \sin 45^\circ \div 1.50 = 0.707 \div 1.50 = 0.471$, so $r = \mathbf{28.1^\circ}$.
2. The faces are parallel, so the normals are parallel and the angle of incidence inside is **28.1°** .
3. The ray reverses its refraction, so it emerges at **45°** , parallel to the incident ray but shifted sideways.

Problem 17 A plastic prism that fails

1. $\sin c = 1 \div 1.52 = 0.658$, so $c = \mathbf{41.1^\circ}$.
2. The angle of incidence is 45° , which is greater than 41.1° , so there is **total internal reflection**.
3. $\sin c = 1 \div 1.38 = 0.725$, $c = \mathbf{46.4^\circ}$. Since 45° is less than 46.4° , some light escapes and the plastic would **not** work well.

Problem 18 Light from underwater

1. $\sin r = 1.33 \times \sin 30^\circ = 1.33 \times 0.500 = 0.665$, so $r = \mathbf{41.7^\circ}$.
2. $\sin r = 1.33 \times \sin 50^\circ = 1.33 \times 0.766 = 1.02$. No angle has a sine above 1, so no refraction is possible: **total internal reflection**.
3. $\sin c = 1 \div 1.33 = 0.752$, $c = \mathbf{48.8^\circ}$, consistent with 30° refracting and 50° reflecting.

Problem 19 Virtual image in a magnifier

1. Draw the ray parallel to the axis (refracting through F) and the ray through the centre; the refracted rays diverge, so extend them back with dashed lines.
2. The image is on the **same side** as the object, **7.5 cm** from the lens, **virtual and upright**, $m = 2.5$, so height = **5.0 mm**.
3. Rays leaving the lens spread out and never meet, so there is no point where light is focused.

Problem 20 Unknown liquid

1. $n = 0.788 \div 0.588 = \mathbf{1.34}$.
2. $\sin c = 1 \div 1.34 = 0.746$, $c = \mathbf{48.3^\circ}$.
3. 45° is less than 48.3° , so the ray **does leave** (it refracts out, with a weak reflection).