



LOGIC BLOOM · PHYSICS · CLASS 12

Ray Optics and Optical Instruments

Mirrors · refraction · total internal reflection · lenses · prisms · dispersion · instruments

NEET, JEE Main and JEE Advanced

Light travels in straight lines and bends only at surfaces. Every formula here is one surface, one sign convention and one equation, used again and again. Learn the sign rule once and the whole chapter follows.

14 Sections

20 Diagrams

Advanced Tier

Practice Set

Fact Sheet

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*Simplest way to
understand the NCERT.*

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1	Plane Mirrors	<i>images on a circle, rays that turn twice</i>
2	Spherical Mirrors	<i>one sign rule for everything</i>
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4	Total Internal Reflection	<i>when no light gets out</i>
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★	One-Page Fact Sheet	<i>every result for revision day</i>

How to Read This Set

Sections 1 to 8 cover the full syllabus for **NEET** and **JEE Main**. Sections 9 to 13 are the **JEE Advanced** layer. Section 14 is a practice set across all three exams.

THE WHOLE CHAPTER IN ONE LINE

One surface at a time. Measure from it. Along the light is positive.

Mirrors, lenses, thick glass balls and lens-mirror systems all fall to this. The image from one surface becomes the object for the next.



THINK IT
THROUGH

WHAT THIS CHAPTER IS WORTH

- It is one of the **highest-scoring chapters** in NEET and JEE Main, often three questions or more.
- Most questions need one formula and a correct sign. The sign is where marks are lost.
- Ray diagrams also come up in board exams, so draw them neatly every time.



TRAP ALERT

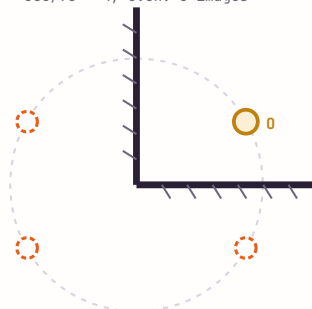
THE HABIT THAT FIXES THIS CHAPTER

- **Put signs on every distance before you touch a formula.**
- Measure every distance from the pole of the mirror or the centre of the lens.
- Distances in the direction the light travels are positive. Against it, negative.
- Heights above the axis are positive. Below it, negative.

A plane mirror forms an image as far behind it as the object is in front. The image is upright and the same size, but turned left to right. Three results built on this come up again and again.

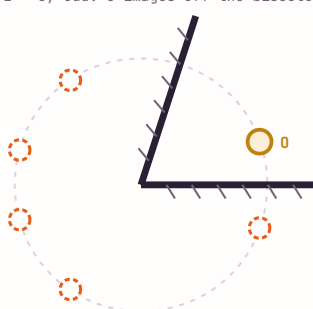
TWO MIRRORS AT AN ANGLE, AND A MIRROR THAT TURNS

MIRRORS AT 90°
 $360/90 = 4$, even: 3 images



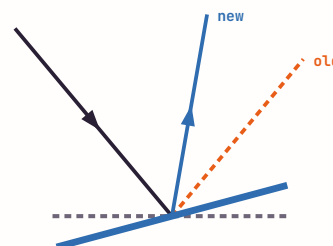
3 images on one circle

MIRRORS AT 72°
 $360/72 = 5$, odd: 5 images off the bisector



5 images (4 if O sits on the bisector)

MIRROR TURNS BY $\theta = 15^\circ$
 the reflected ray turns 30°



Count images with $360/\theta$. A turning mirror swings the reflected ray through twice the angle.

Each image is a reflection of the object or of another image. All of them sit on one circle around the corner.

THREE PLANE MIRROR RESULTS

One reflection turns a ray through $\delta = 180^\circ - 2i$.

Turn the mirror through θ and the reflected ray turns through 2θ .

Two mirrors at angle θ : one bounce off each turns the ray through $360^\circ - 2\theta$, whatever the angle of incidence.

$360/\theta$ IS	WHERE THE OBJECT SITS	NUMBER OF IMAGES
even	anywhere	$\frac{360}{\theta} - 1$
odd	on the bisector	$\frac{360}{\theta} - 1$
odd	off the bisector	$\frac{360}{\theta}$
parallel mirrors	anywhere	endless, in a straight row

WORKED EXAMPLE 1

Two mirrors meet at 60° . A ray reflects off one, then off the other. Through what total angle has it turned?

Use glancing angles g_1 and g_2 , the angles the ray makes with each mirror. Each bounce turns the ray by $2g$.

The ray and the two mirrors form a triangle, so $g_1 + g_2 = 180^\circ - \theta = 120^\circ$.

Total turn $= 2(g_1 + g_2)$.

Answer: 240° , for every angle of incidence

WORKED EXAMPLE 2

A man is 1.8 m tall. His eyes are 10 cm below the top of his head. What is the shortest wall mirror that shows his full height, and how high must its bottom edge be?

Light from his feet reaches his eyes after bouncing halfway between them. So the bottom edge sits at half the eye height: $\frac{1.7}{2} = 0.85$ m.

The same halving works at the top. So the mirror needs half his height.

Answer: 0.9 m long, bottom edge 0.85 m above the floor, at any distance



THINK IT
THROUGH

TWO MORE FACTS THAT KEEP COMING BACK

- Parallel mirrors: each image in one mirror becomes an object for the other. Work outward one image at a time.
- What you can see in a mirror lies inside lines drawn from your image through the mirror's edges. Step closer and you see more.



TRAP ALERT

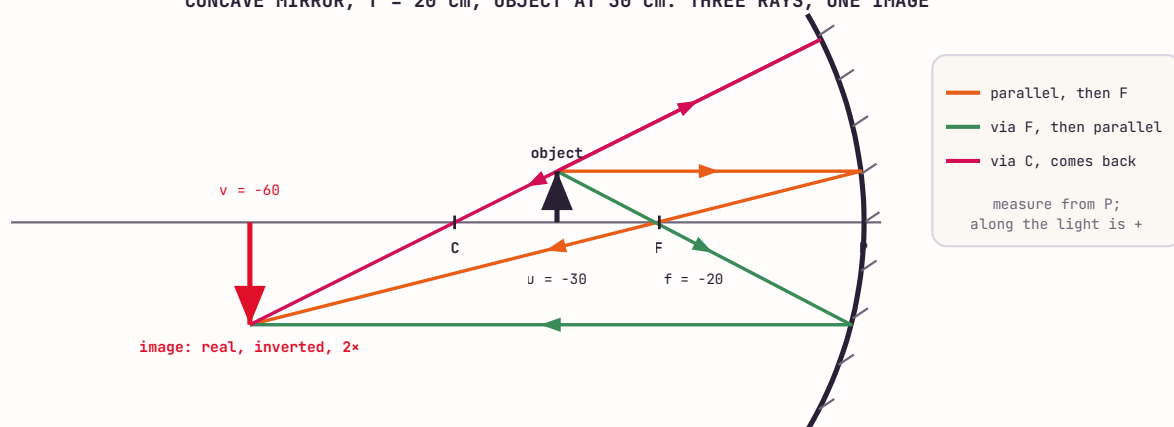
DO NOT USE $360/\theta - 1$ EVERY TIME

- **When $360/\theta$ is odd, the count depends on where the object sits.** Off the bisector it is $360/\theta$.
- A mirror swaps left and right, not top and bottom. That is why ambulance lettering is printed reversed.

Spherical Mirrors

A spherical mirror is a piece of a shiny sphere. Its focal length is half its radius, $f = \frac{R}{2}$. Rays parallel to the axis meet at the focus F after a concave mirror reflects them.

CONCAVE MIRROR, $f = 20$ cm, OBJECT AT 30 cm: THREE RAYS, ONE IMAGE



$1/v + 1/u = 1/f$ gives $v = -60$ cm; $m = -v/u = -2$. Every ray from the tip meets at one point.

Three easy rays from the tip of the object. Any two are enough to find the image.

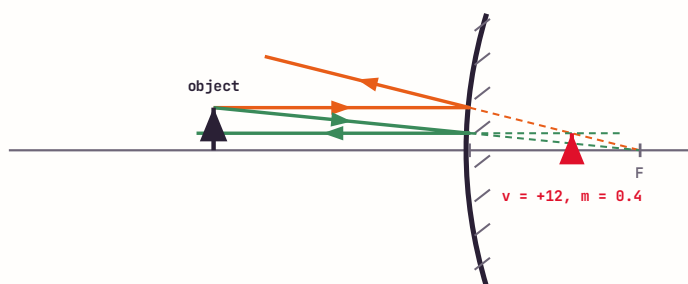
MIRROR FORMULA AND MAGNIFICATION

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \quad m = -\frac{v}{u}$$

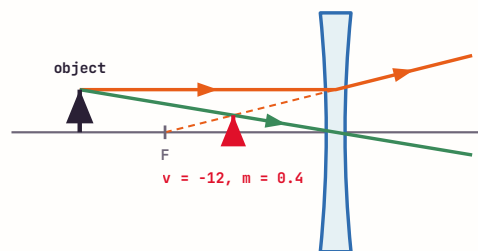
Negative m means the image is upside down. $|m|$ greater than 1 means it is bigger.

OBJECT POSITION (CONCAVE MIRROR)	IMAGE	NATURE
beyond C	between F and C	real, inverted, smaller
at C	at C	real, inverted, same size
between C and F	beyond C	real, inverted, larger
between F and P	behind the mirror	virtual, upright, larger
any position, convex mirror	behind, between P and F	virtual, upright, smaller

THE TWO DIVERGERS: CONVEX MIRROR AND CONCAVE LENS, $f = 20$ cm, OBJECT AT 30 cm



virtual, upright, smaller, behind the mirror



virtual, upright, smaller, same side

Both always give a virtual, upright, smaller image, wherever the real object is.

A convex mirror and a concave lens behave alike. Rays spread out, so the image is always virtual and small.

WORKED EXAMPLE

A car's convex rear-view mirror has $f = 20$ cm. A bus is 1.8 m behind it. Where is the image, and how tall is it compared with the bus?

Signs: $u = -180$ cm. A convex mirror has its focus behind it, so $f = +20$ cm.

$$\frac{1}{v} = \frac{1}{20} - \frac{1}{-180} = \frac{10}{180}, \text{ so } v = +18 \text{ cm, behind the mirror.}$$

$$m = -\frac{18}{-180} = +0.1.$$

Answer: 18 cm behind the mirror, upright, one tenth the size



TRAP ALERT

SIGNS, NOT WORDS

- **Do not put $f = 20$ for every mirror.** Concave: f is negative. Convex: f is positive.
- A real object is always in front, so u is always negative for it.
- If v comes out positive for a mirror, the image is behind it and virtual.

Refraction, Apparent Depth and Lateral Shift

Light slows down in glass or water, so it bends at the surface. The refractive index n measures how much it slows:

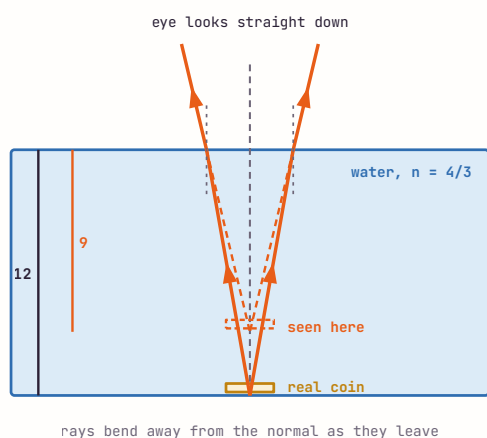
$$n = \frac{c}{v}$$

SNELL'S LAW

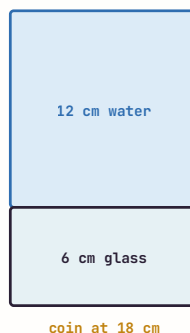
$$n_1 \sin i = n_2 \sin r$$

Going into a denser medium, the ray bends toward the normal. Coming out, it bends away.

A COIN UNDER 12 cm OF WATER LOOKS ONLY 9 cm DEEP



TWO LAYERS: ADD EACH LAYER'S t / n



$$12 / (4/3) = 9$$

$$6 / 1.5 = 4$$

seen at 13 cm

Apparent depth = real depth / n , for a near-straight view. Layers simply add up.

The eye traces the bent rays back in straight lines. They seem to start from a point above the coin.

EFFECT	FORMULA	EXAMPLE
apparent depth, viewed from above	$d_{app} = \frac{d}{n}$	12 cm of water looks 9 cm deep
shift of the image by a slab	$t \left(1 - \frac{1}{n} \right)$	a 6 cm glass slab lifts it 2 cm
sideways shift of a ray through a slab	$\frac{t \sin(i - r)}{\cos r}$	the ray leaves parallel, but shifted

WORKED EXAMPLE

A ray strikes a 6 cm glass slab ($n = 1.5$) at 60° . How far sideways is it shifted when it comes out?

Inside: $\sin r = \frac{\sin 60^\circ}{1.5} = 0.577$, so $r = 35.3^\circ$.

$$\text{Shift} = \frac{6 \sin(60^\circ - 35.3^\circ)}{\cos 35.3^\circ} = \frac{6 \times 0.418}{0.816}.$$

Answer: 3.08 cm, and the ray leaves parallel to how it entered



THINK IT
THROUGH

MEASURING n WITH A TRAVELLING MICROSCOPE

- Focus on a mark on the table. Put a glass slab over it and refocus. Then focus on chalk dust on top.
- The three readings give the real thickness and the apparent thickness.
- Then $n = \text{real thickness} / \text{apparent thickness}$. This is a standard practical.



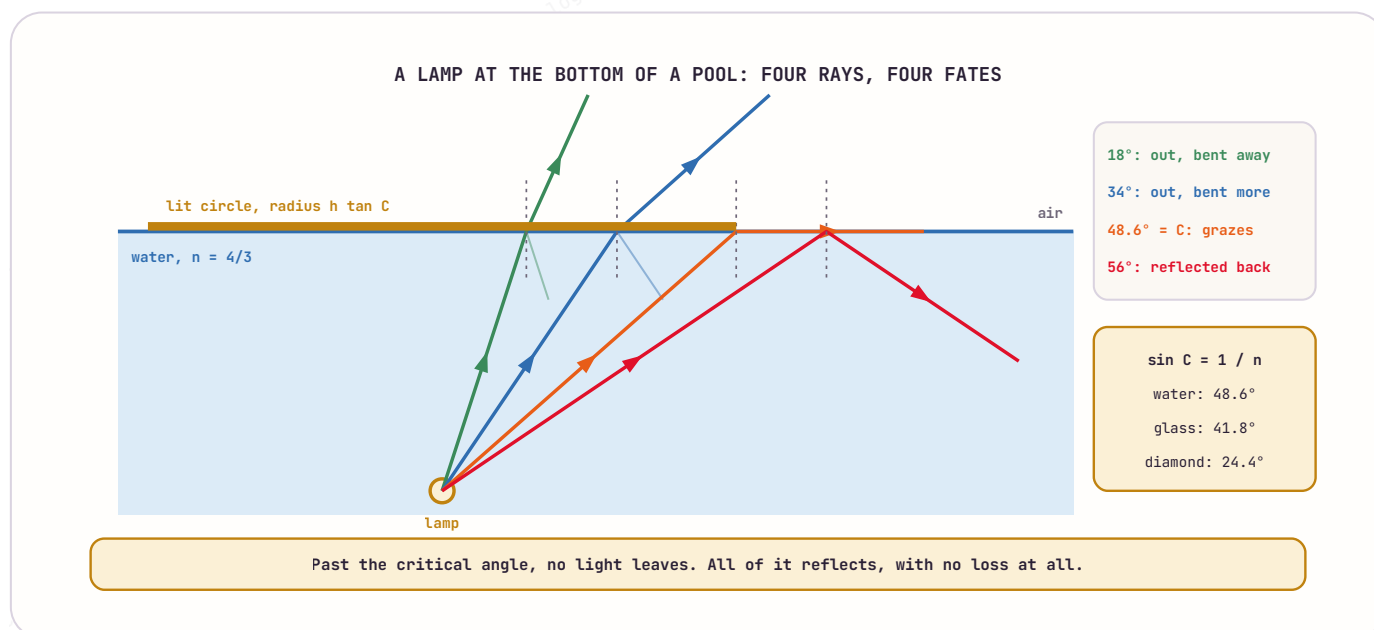
TRAP ALERT

WHICH WAY THE IMAGE MOVES

- **Seen from air, things in water look closer.** Seen from water, things in air look farther.
- The rule d/n works only for a near-straight view. Look at a slant and the depth shrinks even more.

Total Internal Reflection

Going from a dense medium to a lighter one, a ray bends away from the normal. Tilt it far enough and the bent ray skims the surface. Past that angle, no light gets out at all.



As the angle grows, the escaping ray bends more, grazes the surface at C, then reflects back.

THE TWO CONDITIONS

1. Light goes from the denser medium toward the lighter one.
2. The angle inside is larger than the critical angle C, where $\sin C = \frac{1}{n}$.

WHERE IT HAPPENS	WHY
optical fibres	light bounces down the core, see Problem 3
sparkle of a diamond	C is only 24.4° , so light reflects many times inside
mirage on a hot road	hot air near the road is less dense, so light curves up
45° prisms in binoculars	they turn light by 90° or 180° with no loss

WORKED EXAMPLE 1

A lamp sits 2 m deep in a pool ($n = 4/3$). What is the radius of the bright circle on the surface?

Light escapes only within angle C of the vertical. $\sin C = \frac{3}{4}$, so $\tan C = \frac{3}{\sqrt{7}}$.

$$\text{Radius} = h \tan C = \frac{2 \times 3}{\sqrt{7}}.$$

Answer: 2.27 m

WORKED EXAMPLE 2

A 45° - 45° - 90° glass prism turns light through 90° by internal reflection. What is the smallest n that works?

Light enters one short face straight on and meets the long face at 45° .

It must reflect totally, so C must be less than 45° . So $\frac{1}{n} < \sin 45^\circ$.

Answer: n greater than $\sqrt{2} = 1.414$, so ordinary glass (1.5) works



THINK IT
THROUGH

WHY PRISMS BEAT MIRRORS, AND WHAT A FISH SEES

- Total reflection loses no light. Even a good mirror absorbs a few percent.
- That is why binoculars and periscopes use prisms, not mirrors.
- A fish looking up sees the whole sky squeezed into a cone of half-angle C , about 49° . Outside that cone it sees reflections of the pool floor.



TRAP ALERT

DENSE TO LIGHT ONLY

- **Total internal reflection cannot happen going from air into glass.**
- Going into a denser medium, a ray always gets in, whatever the angle.

Refraction at a Curved Surface

A lens is just two curved surfaces. So first learn what one curved surface does. Every lens formula comes from this one.

REFRACTION AT ONE SPHERICAL SURFACE

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

n_1 is where the light starts, n_2 where it goes. R is positive if the centre lies on the far side.

WORKED EXAMPLE 1

An air bubble sits inside a glass ball of $n = 1.5$ and radius 10 cm. It is 4 cm below the surface nearest you. Where does it seem to be?

Light goes from the bubble, through glass, out into air. So $n_1 = 1.5$ and $n_2 = 1$.

Along the light: $u = -4$ cm. The centre of the ball is behind the bubble, on the starting side, so $R = -10$ cm.

$$\frac{1}{v} + \frac{1.5}{4} = \frac{-0.5}{-10}, \text{ so } \frac{1}{v} = 0.05 - 0.375 = -0.325.$$

Answer: 3.08 cm below the surface, a little shallower than it is

TWO SURFACES MAKE A LENS: THE LENS MAKER'S FORMULA

$$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

In a liquid of index n_m , replace $(n - 1)$ by $\left(\frac{n}{n_m} - 1\right)$.

WORKED EXAMPLE 2

A glass lens ($n = 1.5$) has both faces of radius 20 cm, bulging outward. Find f in air, then in water ($n = 4/3$).

Signs: $R_1 = +20$, $R_2 = -20$. In air: $\frac{1}{f} = 0.5 \left(\frac{1}{20} + \frac{1}{20} \right) = \frac{1}{20}$.

In water: $\frac{n}{n_m} - 1 = \frac{1.5}{4/3} - 1 = 0.125$. So $\frac{1}{f} = 0.125 \times \frac{1}{10}$.

Answer: 20 cm in air, 80 cm in water



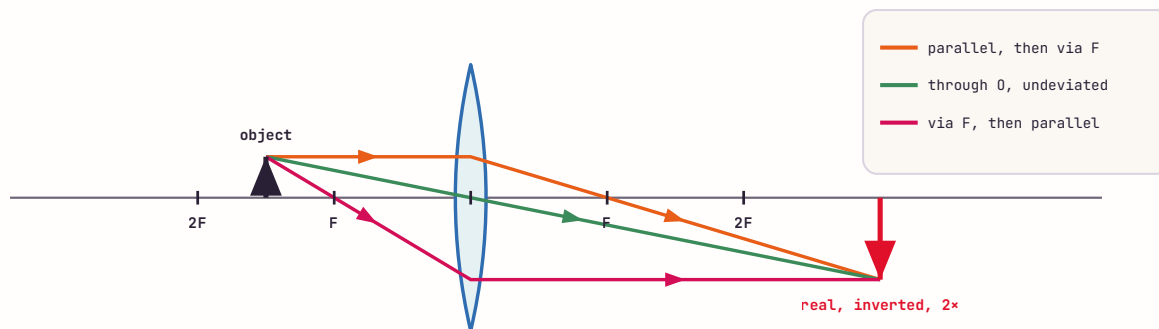
A LENS CAN SWITCH SIDES

- **Put a glass lens in a liquid denser than glass and it flips.** A converging lens then diverges.
- In a liquid with the same index as the glass, the lens vanishes. It has no power at all.

Thin Lenses and Power

A convex lens brings parallel light to a focus. A concave lens spreads it, as if from a focus in front. One formula covers both, with the same sign rule as before.

CONVEX LENS, $f = 10$ cm, OBJECT AT 15 cm: IMAGE AT 30 cm, TWICE AS TALL



$$1/v - 1/u = 1/f: 1/30 - 1/(-15) = 1/10. m = v/u = -2.$$

Three rays again. The ray through the centre does not bend at all.



▶ PLAY

RAY DIAGRAMS STILL CONFUSING?

Drag the object and watch the image move.

Slide the object along the axis. The three rays redraw, and the image flips from real to virtual as you cross F. logicbloom.co.in/download · Free to start.



SCAN

LENS FORMULA, MAGNIFICATION AND POWER

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad m = \frac{v}{u} \quad P = \frac{1}{f}$$

Power is in dioptres when f is in metres. Lenses in contact simply add: $P = P_1 + P_2$.

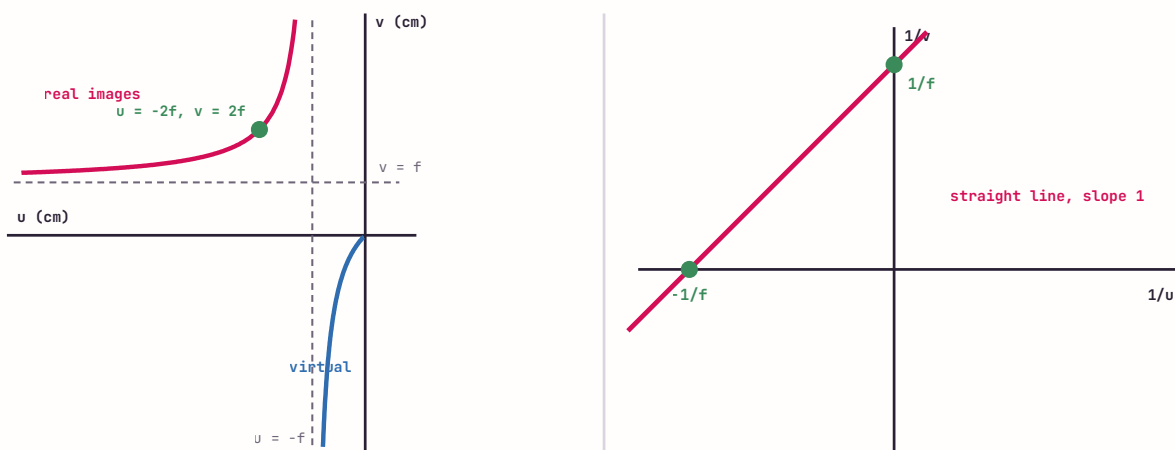
THREE MORE LENS RESULTS

Newton's form: measure x and y from the two foci. Then $xy = f^2$.

A real image of a real object on a screen needs a gap $D \geq 4f$ between them.

Two thin lenses a distance d apart: $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$

CONVEX LENS, $f = 20$ cm: THE u - v GRAPH AND THE $1/u$ - $1/v$ GRAPH



The intercepts give f at once. That is why the $1/u$ - $1/v$ graph is the one asked in practicals.

Real images sit on the upper branch. The straight-line graph shows f at both intercepts.

WORKED EXAMPLE

A convex lens of $f = 20$ cm touches a concave lens of $f = 30$ cm. Find the combined power and focal length.

$$P_1 = \frac{100}{20} = +5 \text{ D and } P_2 = -\frac{100}{30} = -3.33 \text{ D.}$$

$$\text{Total } P = +1.67 \text{ D, so } f = \frac{100}{1.67} \text{ cm.}$$

Answer: +1.67 D, a converging lens of $f = 60$ cm



THINK IT
THROUGH

CUTTING A LENS

- Cut a lens across the axis into top and bottom halves. Each half keeps the same f . The image is the same, only dimmer.
- Cut it along the axis into two plano-convex halves. Each half has twice the focal length.
- Put the two halves back together and the powers add again to the original.



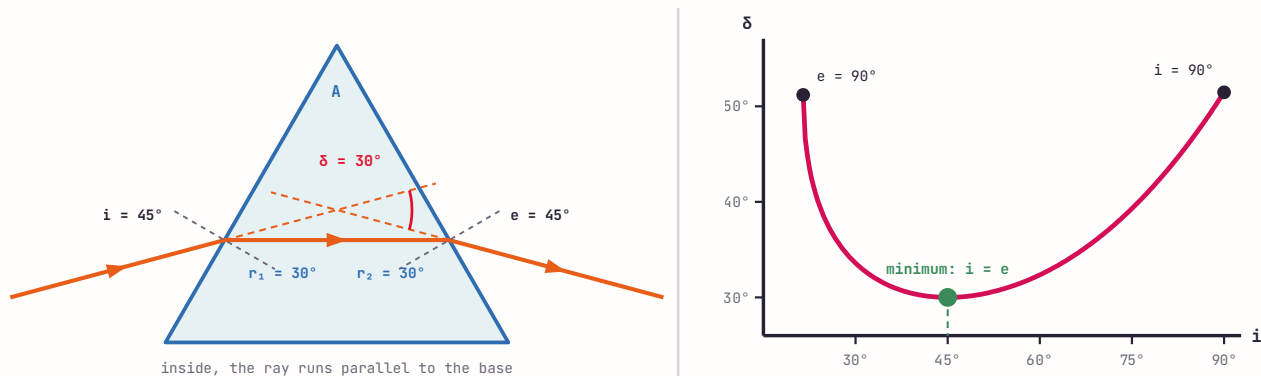
TRAP ALERT

MIRROR AND LENS FORMULAS DIFFER BY ONE SIGN

- **Mirror: $1/v + 1/u$. Lens: $1/v - 1/u$.** Mixing them up is the most common slip in this chapter.
- Magnification also flips: $m = -v/u$ for a mirror, but $m = v/u$ for a lens.

A prism bends light twice, once at each face, and both bends turn it the same way. The total turn is the **deviation** δ .

PRISM, $A = 60^\circ$, $n = \sqrt{2}$: THE PATH AT MINIMUM DEVIATION, AND THE δ - i CURVE



At minimum deviation $n = \sin((A + \delta)/2) / \sin(A/2) = \sin 45^\circ / \sin 30^\circ = \sqrt{2}$.

Raise the angle of incidence and the deviation first falls, then rises. The bottom is where the path is symmetric.

PRISM RELATIONS

$$r_1 + r_2 = A \quad \delta = i + e - A$$

At minimum deviation: $i = e$, $r_1 = r_2 = \frac{A}{2}$, and $n = \frac{\sin \frac{A + \delta_m}{2}}{\sin \frac{A}{2}}$

Thin prism, small A : $\delta = (n - 1)A$

WORKED EXAMPLE 1

A ray falls straight onto one face of a 30° prism of $n = \sqrt{2}$. Find the angle it comes out at, and its deviation.

Straight on means $i = 0$ and $r_1 = 0$. So $r_2 = A = 30^\circ$.

At the second face: $\sin e = \sqrt{2} \sin 30^\circ = 0.707$, so $e = 45^\circ$.

$$\delta = i + e - A = 0 + 45^\circ - 30^\circ.$$

Answer: it leaves at 45° , turned through 15°

WORKED EXAMPLE 2

A thin prism of angle 4° has $n = 1.5$. How far does it turn a ray?

$\delta = (n - 1)A = 0.5 \times 4^\circ$. For a thin prism this holds for any small angle of incidence.

Answer: 2°



THINK IT
THROUGH

COLOURS SPLIT, AND SECTION 9 CONTROLS IT

- n is slightly larger for violet light than for red. So violet turns more.
- White light spreads into a band of colours, called a spectrum.
- JEE Advanced asks how to cancel this spread, or the bend. Section 9 covers both.



TRAP ALERT

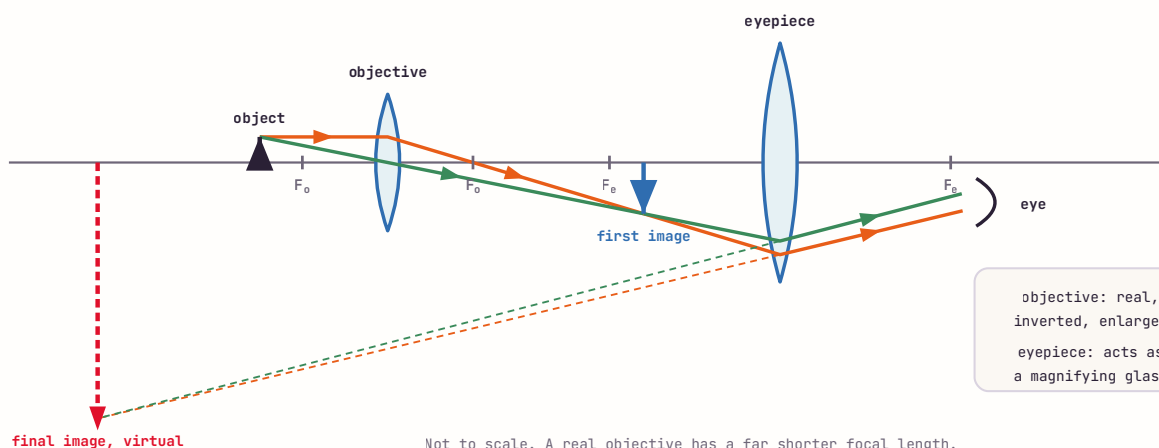
WHEN LIGHT CANNOT GET OUT

- **If A is more than twice C , no ray can leave the second face.**
- Every ray then meets that face beyond the critical angle and reflects back inside.

An instrument makes something look bigger by making it fill a bigger angle at the eye. $D = 25 \text{ cm}$ is the closest distance at which a normal eye sees clearly.

INSTRUMENT	IMAGE AT INFINITY (RELAXED EYE)	IMAGE AT $D = 25 \text{ cm}$ (MOST MAGNIFICATION)
simple microscope	$m = \frac{D}{f}$	$m = 1 + \frac{D}{f}$
compound microscope	$m \approx \frac{L}{f_o} \cdot \frac{D}{f_e}$	$m = \frac{v_o}{u_o} \left(1 + \frac{D}{f_e} \right)$
astronomical telescope	$m = \frac{f_o}{f_e}$, length $f_o + f_e$	$m = \frac{f_o}{f_e} \left(1 + \frac{f_e}{D} \right)$

COMPOUND MICROSCOPE: TWO LENSES, TWO STAGES OF MAGNIFICATION



Not to scale. A real objective has a far shorter focal length.

$$M = m_o \times m_e \approx (L / f_o) \times (D / f_e). \text{ Both lenses multiply.}$$

The objective makes a real, enlarged image. The eyepiece then magnifies that image again.

WORKED EXAMPLE 1

A microscope has $f_o = 1 \text{ cm}$ and $f_e = 5 \text{ cm}$. An object sits 1.1 cm from the objective. The final image forms at 25 cm . Find the magnification and the lens separation.

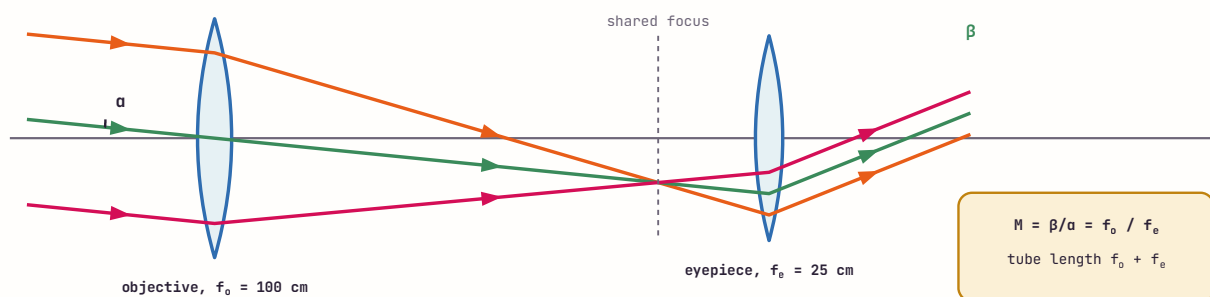
Objective: $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$, so $v_o = 11 \text{ cm}$ and $m_o = -10$.

Eyepiece: $m_e = 1 + \frac{25}{5} = 6$. It must hold the first image $\frac{25}{6} = 4.17 \text{ cm}$ in front of it.

Total $|m| = 10 \times 6 = 60$. Separation $= 11 + 4.17$.

Answer: magnification 60, lenses 15.2 cm apart

ASTRONOMICAL TELESCOPE IN NORMAL ADJUSTMENT: ANGLES, NOT SIZES, GET BIGGER



Starlight enters parallel and leaves parallel, but tilted 4 times more. The star looks 4 times bigger.

A telescope cannot make a distant star bigger. It makes the angle bigger, here by $f_o/f_e = 4$.

WORKED EXAMPLE 2

A telescope has $f_o = 100$ cm and $f_e = 5$ cm. Find the magnification and length for a relaxed eye, then with the image at 25 cm.

Relaxed: $m = \frac{100}{5} = 20$, length $100 + 5 = 105$ cm.

At 25 cm: $m = 20\left(1 + \frac{5}{25}\right) = 24$. The eyepiece must sit 4.17 cm from the first image, so the length is 104.2 cm.

Answer: 20 and 105 cm; then 24 and 104.2 cm



TRAP ALERT

MICROSCOPE AND TELESCOPE WANT OPPOSITE LENSES

- **A microscope wants both focal lengths short.** A telescope wants a long objective and a short eyepiece.
- A telescope objective is also wide, to collect more light from faint stars.

The JEE Advanced layer

Everything so far is complete for NEET and JEE Main. From here each problem needs a route you build yourself. No single formula reaches the answer.

9 Dispersion and Achromatism

A thin prism turns each colour by $(n - 1)A$. Violet has the larger n , so it turns more than red. Pair two different glasses and you can cancel either the spread or the turn.

MEASURING THE SPREAD

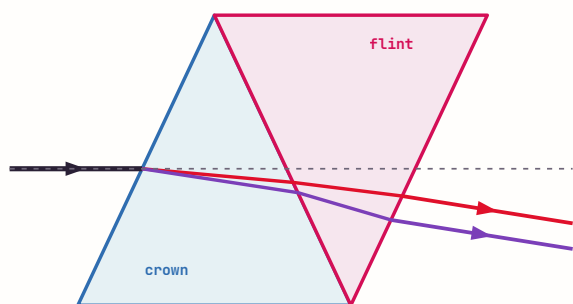
Angular dispersion: $\delta_v - \delta_r = (n_v - n_r)A$

Mean deviation, for yellow light: $\delta_y = (n_y - 1)A$

Dispersive power: $\omega = \frac{n_v - n_r}{n_y - 1}$, so the spread is $\omega \delta_y$

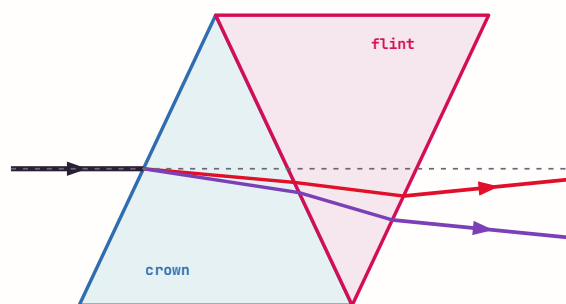
TWO THIN PRISMS OF DIFFERENT GLASS, PLACED TOGETHER (ANGLES EXAGGERATED)

DEVIATION WITHOUT DISPERSION



colours leave parallel, but bent
 $\omega_1 \delta_1 + \omega_2 \delta_2 = 0$

DISPERSION WITHOUT DEVIATION



colours fan out, centre ray unbent
 $(n_1 - 1)A_1 = (n_2 - 1)A_2$

Flint spreads colours about twice as much as crown for the same bend. That is what makes both tricks work.

Turn the second prism upside down and it undoes the first. Its angle decides whether it cancels the spread or the bend.

GOAL	CONDITION	WHAT IS LEFT
deviation without dispersion	$\omega_1 \delta_1 + \omega_2 \delta_2 = 0$	a net bend, no colours
dispersion without deviation	$(n_1 - 1)A_1 = (n_2 - 1)A_2$	colours, no net bend
achromatic lens pair	$\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0$	one focus for red and violet

WORKED EXAMPLE 1

A 6° crown prism has $n_v = 1.53$ and $n_r = 1.51$. A flint prism with $n_v = 1.68$, $n_r = 1.64$ and $n_y = 1.66$ is paired with it to remove the colours. Find the flint angle and the net deviation.

The spreads must cancel: $(1.53 - 1.51) \times 6 = (1.68 - 1.64)A_2$, so $A_2 = 3^\circ$.

The crown bends by $0.52 \times 6 = 3.12^\circ$. The flint bends back by $0.66 \times 3 = 1.98^\circ$.

Answer: 3° , leaving a net deviation of 1.14° with no colour

WORKED EXAMPLE 2

A lens has $f = 20$ cm for yellow light. Its glass has $\omega = 0.05$. How far apart are the red and violet foci?

Each colour has its own n , so its own f . Since $\frac{1}{f}$ is proportional to $(n - 1)$, the change is $\frac{\Delta f}{f} = \omega$.

$$f_r - f_v = \omega f = 0.05 \times 20.$$

Answer: 1 cm, with violet focusing nearer the lens



THINK IT
THROUGH

WHY AN ACHROMATIC PAIR NEEDS TWO GLASSES

- With one glass, ω is the same in both lenses. Then the condition forces $f_1 = -f_2$.
- Equal and opposite lenses have zero total power, so the pair does nothing.
- So a camera lens pairs a convex crown lens with a weaker concave flint lens.



TRAP ALERT

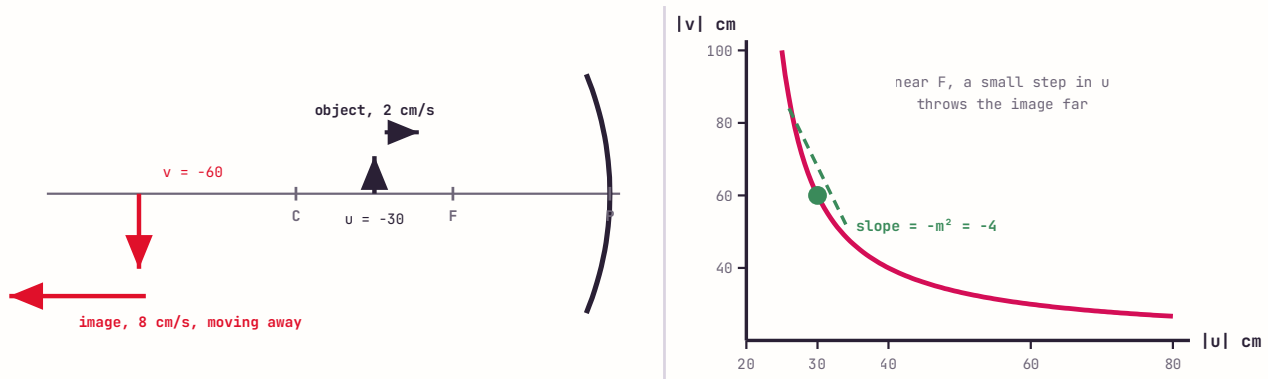
THE SPREAD DEPENDS ON $n_v - n_r$, NOT ON n

- **A larger n does not mean a larger spread.** Flint spreads colours about twice as much as crown.
- Work out ω from the colour indices, not from the yellow index alone.

Images in Motion and Along the Axis

If the object moves, the image moves too, but not at the same speed. Differentiate the mirror or lens formula with respect to time to find out how fast.

OBJECT MOVES TOWARD A CONCAVE MIRROR AT 2 cm/s. THE IMAGE MOVES AT 8 cm/s



Along the axis, image speed = $m^2 \times$ object speed. Here $m = -2$, so $4 \times 2 = 8$ cm/s.

Near F, a small move of the object sends the image a long way. The slope of this curve is the speed ratio.



▶ PLAY

IMAGE SPEED STILL A MYSTERY?

Move the object and race its image.

Push the object toward the mirror. Watch the image speed up near F and jump to the other side. logicbloom.co.in/download · Free to start.



SCAN

SPEED OF THE IMAGE ALONG THE AXIS

Mirror: $\frac{dv}{dt} = -m^2 \frac{du}{dt}$ the image moves the opposite way along the axis.

Lens: $\frac{dv}{dt} = +m^2 \frac{du}{dt}$ the image moves the same way as the object.

Across the axis, at a fixed distance: the image moves at m times the object's speed.

WORKED EXAMPLE

An object 15 cm from a convex lens ($f = 10$ cm) moves toward the lens at 1 cm/s. How fast does the image move, and which way?

From section 5, the image is at 30 cm and $m = -2$.

For a lens, $\frac{dv}{dt} = m^2 \frac{du}{dt} = 4 \times 1$.

The object moves toward the lens, in the direction of the light. So does the image, which means away from the lens.

Answer: 4 cm/s, moving away from the lens

WORKED EXAMPLE 2

An object sits 30 cm in front of a concave mirror ($f = 20$ cm). It moves straight up, across the axis, at 2 cm/s. How does the image move?

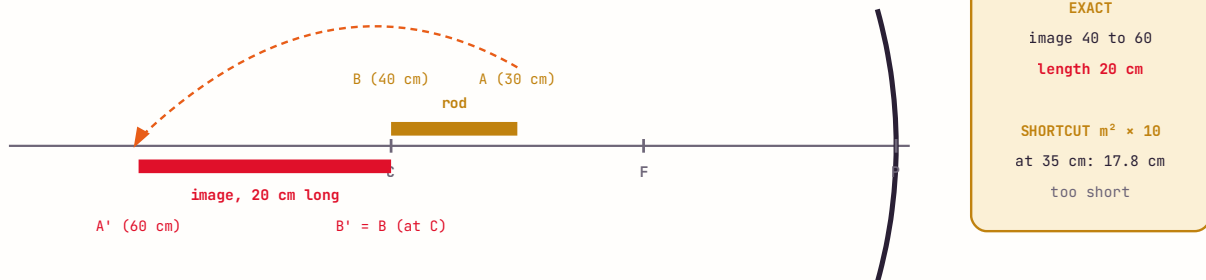
The distance stays 30 cm, so $m = -2$ stays fixed.

Image height $= m \times$ object height. So the image moves at $2 \times 2 = 4$ cm/s.

m is negative, so it moves the opposite way: downward.

Answer: 4 cm/s, downward

A 10 cm ROD ALONG THE AXIS OF A CONCAVE MIRROR, $f = 20$ cm, FROM 30 cm TO 40 cm



For a long object, image both ends separately. m^2 works only for short objects.

The near end of the rod maps far away, and the point at C maps onto itself. The image is reversed and twice as long.

AN OBJECT LYING ALONG THE AXIS

Short object: its image length is m^2 times its length, for both mirrors and lenses.

Long object: m changes along it, so find the image of each end separately.

WORKED EXAMPLE 3

You walk toward a plane mirror at 1 m/s. The mirror moves toward you at 2 m/s. How fast does your image approach you?

For a plane mirror, along its normal: image velocity = $2 \times \text{mirror velocity} - \text{object velocity}$.

Take your walking direction as positive. Mirror: -2 m/s. Image: $2(-2) - 1 = -5$ m/s.

You move at +1 m/s, so the gap closes at $5 + 1$ m/s.

Answer: 6 m/s



A PLANE MIRROR IS THE EASY CASE

- **Only the part of velocity at right angles to a plane mirror flips.** The part along it stays.
- If the mirror itself moves at v toward you, your image moves at $2v$ toward you.

Media with a Changing Index

In air or liquid whose n changes from place to place, there is no single surface. The ray bends a little everywhere, so its path curves.

THE RULE THAT REPLACES SNELL'S LAW

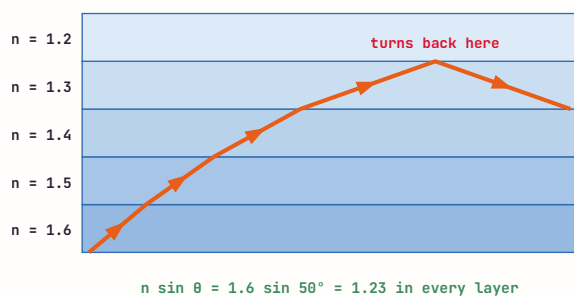
Slice the medium into thin layers of constant n . Snell's law at every boundary gives

$$n \sin \theta = \text{constant}$$

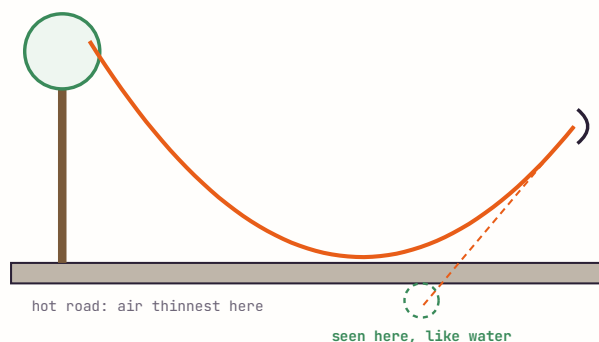
θ is measured from the direction in which n changes. The ray always curves toward higher n .

WHEN n CHANGES SMOOTHLY, $n \sin \theta$ STAYS THE SAME AND THE RAY CURVES

rising into thinner layers, it bends away from the normal, then turns back



MIRAGE ON A HOT ROAD

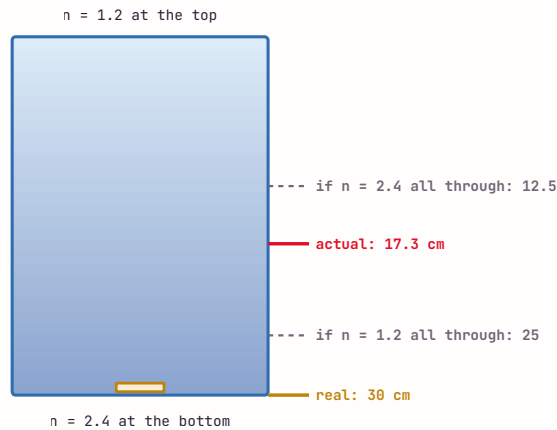


A mirage is not a reflection from a surface. It is a ray bent upward by air of smoothly changing n .

Each layer bends the ray a little more. Once $n \sin \theta$ cannot be met, the ray turns back.

EFFECT	WHAT IS HAPPENING
mirage on a hot road	thin hot air at the road bends light from the sky up into the eye
looming at sea	cold dense air over the water bends light down, so far ships look raised
sunrise seen early	denser air near the ground bends sunlight round the curve of the Earth

A LIQUID WHOSE INDEX GROWS WITH DEPTH: $n = 1.2(1 + y/H)$, $H = 30$ cm



SLICE IT INTO THIN LAYERS

each slice dy looks dy / n deep

$$\text{apparent depth} = \int dy / n$$

$$= (H / 1.2) \ln 2$$

$$= 25 \times 0.693 = 17.3 \text{ cm}$$

Not an average of 1.2 and 2.4. The integral weights the low-index top layers more.

Each thin layer looks shallower by its own n . Add the layers with an integral.

WORKED EXAMPLE

A tank holds 30 cm of a liquid whose index grows with depth y as $n = 1.2(1 + y/30)$. How deep does a coin at the bottom look from straight above?

A thin layer dy at depth y looks $\frac{dy}{n}$ thick. Add them all up.

$$d_{app} = \int_0^{30} \frac{dy}{1.2(1 + y/30)} = \frac{30}{1.2} \ln 2 = 25 \times 0.693.$$

Answer: 17.3 cm



TRAP ALERT

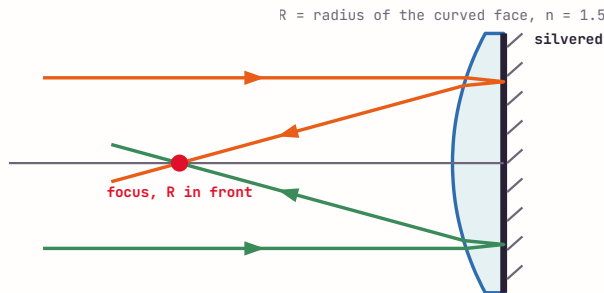
MEASURE θ FROM THE DIRECTION n CHANGES IN

- For layers stacked vertically, θ is the angle with the vertical.
- Using the angle with the layers turns sin into cos, and the path comes out wrong.

Silvered Lenses and Lens-Mirror Systems

When light meets several surfaces, take them one at a time. The image from one becomes the object for the next.

SILVER THE FLAT FACE OF A PLANO-CONVEX LENS AND IT BECOMES A CONCAVE MIRROR



TREAT IT AS ONE MIRROR

$$P = 2 P_{\text{lens}} + P_{\text{mirror}}$$

Light crosses the lens twice,
then reflects once

FLAT SIDE SILVERED

$$P_{\text{mirror}} = 0$$

$$f = R / 2(n - 1)$$

$$= R \text{ for } n = 1.5$$

CURVED SIDE SILVERED

$$P_{\text{mirror}} = 2/R$$

$$f = R / 2n$$

$$= R/3 \text{ for } n = 1.5$$

Light passes the lens, bounces, and passes it again. Count each pass as a power.

The light crosses the lens, reflects, and crosses the lens again. Together they act as one concave mirror.

WORKED EXAMPLE 1

A plano-convex lens ($n = 1.5$, $R = 20$ cm) is silvered on its curved face. An object is 10 cm in front. Where is the image?

Curved side silvered: $f = \frac{R}{2n} = \frac{20}{3} = 6.67$ cm, acting as a concave mirror.

Mirror formula: $\frac{1}{v} = \frac{1}{-6.67} - \frac{1}{-10} = -0.15 + 0.1 = -0.05$, so $v = -20$ cm.

Answer: a real image 20 cm in front of the lens

WORKED EXAMPLE 2

A convex lens ($f = 20$ cm) has a plane mirror 10 cm behind it. An object is 30 cm in front of the lens. Find the final image.

Lens, first pass: $\frac{1}{v} = \frac{1}{20} - \frac{1}{30}$, so the light heads for a point 60 cm behind the lens.

That point is 50 cm behind the mirror. The mirror sends it back toward a point 50 cm in front of the mirror. That is 40 cm in front of the lens.

Lens, second pass: the light now travels the other way, so take that as positive. The object is virtual, at $u = +40$.

$\frac{1}{v} = \frac{1}{20} + \frac{1}{40} = \frac{3}{40}$, so $v = 13.3$ cm.

Answer: a real image 13.3 cm in front of the lens, on the object's side

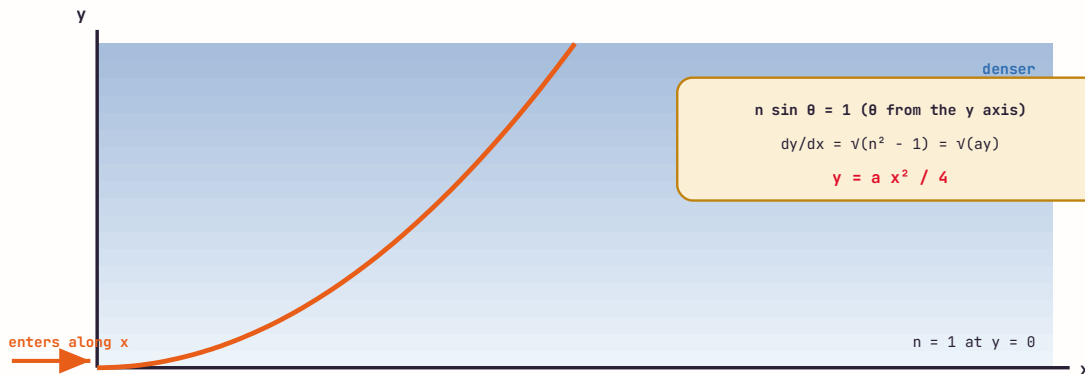


RESET THE SIGN RULE AFTER EVERY REFLECTION

- **After a mirror, the light travels the other way.** So positive now points the other way too.
- Measure each distance from the surface the light is about to meet.

Each problem uses a different technique. None of them can be solved by recalling one formula.

$n = \sqrt{1 + ay}$: A RAY ENTERING SIDEWAYS CURVES INTO A PARABOLA



The ray bends toward higher n at every step. The bending adds up to a parabola.

PROBLEM 1 • CALCULUS

A medium has $n = \sqrt{1 + ay}$, with y measured upward and a a positive constant. A ray enters at the origin, travelling along the x axis. Find the shape of its path.

What it demands: turning $n \sin \theta = \text{constant}$ into a differential equation for the path, then integrating it

At the origin $n = 1$ and the ray makes 90° with the y axis. So $n \sin \theta = 1$ all along the path.

The slope is $\frac{dy}{dx} = \cot \theta$. With $\sin \theta = \frac{1}{n}$, this gives $\cot \theta = \sqrt{n^2 - 1} = \sqrt{ay}$.

Separate and integrate: $\frac{dy}{\sqrt{y}} = \sqrt{a} dx$, so $2\sqrt{y} = \sqrt{a} x$.

Answer: a parabola, $y = \frac{ax^2}{4}$

PROBLEM 2 • CONSTRUCTION

An object and a screen are 100 cm apart. A convex lens between them gives a sharp image at two positions, 20 cm apart. The two images are 9 cm and 4 cm tall. Find f and the object's height.

What it demands: seeing that the two positions swap u and v . Then the product of the magnifications gives the height

The two positions swap u and v . So $u + v = 100$ and $v - u = 20$, giving 40 cm and 60 cm.

$$\frac{1}{f} = \frac{1}{60} + \frac{1}{40}, \text{ so } f = 24 \text{ cm. In general } f = \frac{D^2 - d^2}{4D}.$$

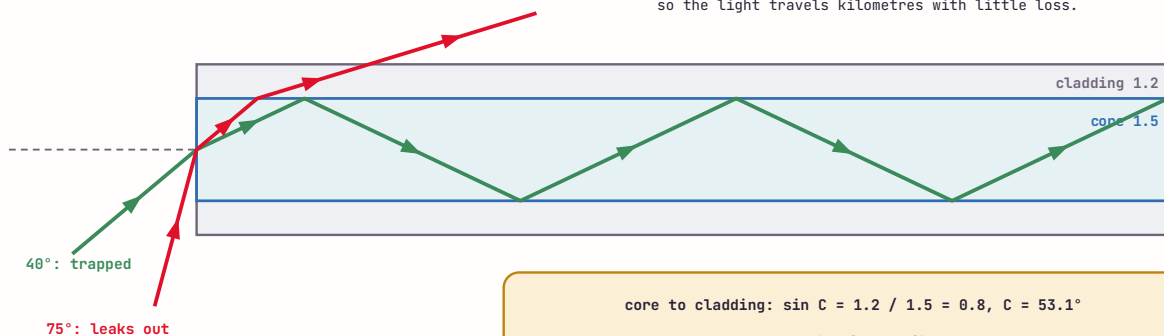
The two magnifications multiply to 1. So the object height is $\sqrt{9 \times 4} = 6$ cm.

Two positions exist only if $D \geq 4f$. Here 100 is just above 96.

Answer: $f = 24$ cm, and the object is 6 cm tall

OPTICAL FIBRE: CORE $n = 1.5$, CLADDING $n = 1.2$, IN AIR

Each bounce is a total internal reflection, so the light travels kilometres with little loss.



A ray inside the acceptance cone always meets the wall beyond C . A steeper ray leaks out.

PROBLEM 3 • ONE OR MORE CORRECT

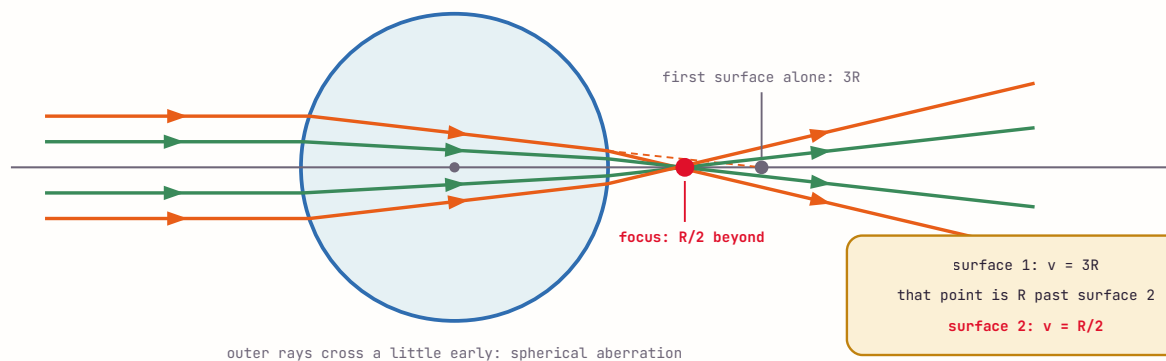
An optical fibre has a core of $n = 1.5$ and a cladding of $n = 1.2$. Which of these are correct?

What it demands: linking refraction at the end face with total reflection at the wall, then changing the outside medium

- (A) the critical angle at the core wall is $\sin^{-1} 0.8$.
- (B) in air, light entering within 64.2° of the axis is guided.
- (C) dipped in water ($n = 4/3$), the fibre accepts a wider cone.
- (D) any ray entering at a smaller angle than the limit meets the wall beyond C
- (A) $\sin C = \frac{1.2}{1.5} = 0.8$. True.
- (B) At the limit, $\sin \theta = 1.5 \cos C = 1.5 \times 0.6 = 0.9$, so $\theta = 64.2^\circ$. True.
- (C) In water, $\sin \theta = \frac{0.9}{4/3} = 0.675$, so $\theta = 42.5^\circ$. The cone gets narrower. False.
- (D) A smaller entry angle gives a flatter ray inside, which meets the wall at a larger angle of incidence. True.

Answer: (A), (B) and (D)

PARALLEL LIGHT THROUGH A GLASS BALL, $n = 1.5$: TWO SURFACES, ONE FOCUS



Use $n_2/v - n_1/u = (n_2 - n_1)/R$ at each surface, moving the origin to that surface.

The first surface aims the light at $3R$. The second surface catches it early and brings it to $R/2$ beyond.

PROBLEM 4 • TWO SURFACES • NUMERICAL

A solid glass ball ($n = 1.5$) has radius 2 cm. Parallel light falls on it. How far beyond the far surface does it focus? Give the answer in cm to two decimal places.

What it demands: two refractions in a row. The origin moves to the second surface, and the object there is virtual

First surface: $\frac{1.5}{v} = \frac{0.5}{2}$, so $v = 6$ cm from the near surface.

The far surface is 4 cm away. So the light heads for a point 2 cm beyond it: a virtual object, $u = +2$.

Second surface, glass to air, $R = -2$: $\frac{1}{v} - \frac{1.5}{2} = \frac{-0.5}{-2}$, so $\frac{1}{v} = 1$.

Answer: 1.00 cm

A BIRD DIVES AT 6 m/s, A FISH RISES AT 3 m/s. EACH SEES A DIFFERENT CLOSING SPEED

WHAT THE FISH SEES

image: 4 m up
bird: 3 m up

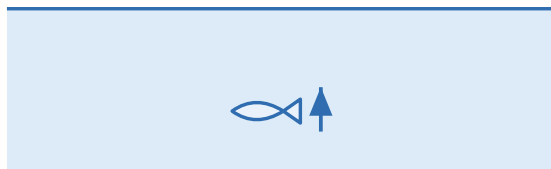


image of bird moves at $\frac{4}{3} \times 6 = 8$ m/s
closing speed $8 + 3 = 11$ m/s

WHAT THE BIRD SEES

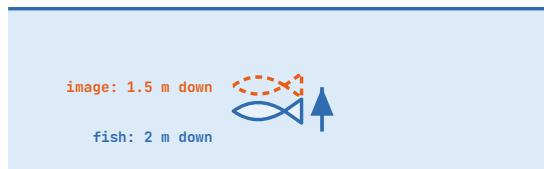


image: 1.5 m down
fish: 2 m down
image of fish moves at $3 \times \frac{3}{4} = 2.25$ m/s
closing speed $6 + 2.25 = 8.25$ m/s

Distances in water look $\times \frac{3}{4}$ from air. Distances in air look $\times \frac{4}{3}$ from water.

Each animal sees the other's image, not the animal. The images move at different speeds.

PROBLEM 5 • RELATIVE MOTION

A bird dives toward still water at 6 m/s. Right below it, a fish rises at 3 m/s. Take $n = \frac{4}{3}$. How fast does each see the other approach?

What it demands: differentiating apparent depth, then adding the observer's own speed; the two answers are not equal

The fish sees the bird at $\frac{4}{3}$ times its height. So the bird's image falls at $\frac{4}{3} \times 6 = 8$ m/s.

The bird sees the fish at $\frac{3}{4}$ of its depth. So the fish's image rises at $\frac{3}{4} \times 3 = 2.25$ m/s.

Fish's view: $8 + 3 = 11$ m/s. Bird's view: $6 + 2.25 = 8.25$ m/s.

Answer: the fish sees 11 m/s, the bird sees 8.25 m/s

14 Practice Set

Questions 1 to 9 are NEET and JEE Main level. Questions 10 to 15 are JEE Advanced, in its real formats. Try each one before reading the answers on the next page.

NEET and JEE Main

Q1 JEE MAIN • LEVEL 2 • SINGLE CORRECT

A concave mirror of focal length 15 cm forms a real image three times the size of the object. How far is the object from the mirror?

- (A) 10 cm (B) 20 cm
(C) 45 cm (D) 60 cm

Q2 NEET • LEVEL 2 • SINGLE CORRECT

Two plane mirrors meet at 72° . An object sits between them, but not on the bisector. How many images are formed?

- (A) 4 (B) 6
(C) 5 (D) 3

Q3 JEE MAIN • LEVEL 2 • SINGLE CORRECT

A beaker holds 8 cm of water ($n = 4/3$) with 6 cm of oil ($n = 1.5$) floating on top. Seen from straight above, how deep does the bottom look?

- (A) 10 cm (B) 14 cm
(C) 9.9 cm (D) 12 cm

Q4 JEE MAIN • LEVEL 2 • SINGLE CORRECT

Light travels from glass ($n = 1.5$) toward water ($n = 4/3$). The critical angle at this boundary is:

- (A) $\sin^{-1}(2/3)$ (B) $\sin^{-1}(3/4)$
(C) $\sin^{-1}(9/8)$ (D) $\sin^{-1}(8/9)$

Q5 JEE MAIN • LEVEL 2 • SINGLE CORRECT

A biconvex glass lens ($n = 1.5$) has $f = 20$ cm in air. It is dipped in a liquid of $n = 1.6$. Its focal length becomes:

- (A) +160 cm (B) -160 cm
(C) +32 cm (D) -20 cm

Q6 JEE MAIN • LEVEL 2 • NUMERICAL

A convex lens and a concave lens, each of focal length 20 cm, share an axis 10 cm apart. Find the focal length of the pair in cm. Round off to the nearest integer.

Q7 NEET • LEVEL 2 • SINGLE CORRECT

An astronomical telescope in normal adjustment magnifies 30 times and is 62 cm long. The focal length of its eyepiece is:

- (A) 2 cm (B) 60 cm
(C) 2.07 cm (D) 1.94 cm

Q8 JEE MAIN • LEVEL 2 • SINGLE CORRECT

For a convex lens, the graph of $1/v$ against $1/u$ cuts the $1/v$ axis at 0.05 cm^{-1} . An object is placed 30 cm from the lens. The magnification is:

- (A) +2 (B) -0.5
(C) -2 (D) -0.4

Q9 JEE MAIN • LEVEL 2 • SINGLE CORRECT

Two plane mirrors face each other 20 cm apart. An object is 5 cm from mirror M_1 . How far apart are the two images nearest to M_1 , seen in M_1 ?

- (A) 40 cm (B) 10 cm
(C) 20 cm (D) 30 cm

JEE Advanced

Q10 JEE ADVANCED • LEVEL 3 • ONE OR MORE CORRECT

An object moves along the axis toward a concave mirror ($f = 20 \text{ cm}$). It starts far away and keeps a steady speed. Which of the following are correct?

- (A) When the object is at C, the image moves exactly as fast as the object. (B) While the object is beyond F, the image moves away from the mirror.
(C) The image is fastest just before the object reaches F. (D) As the object reaches the pole, the image stops moving.

Q11 JEE ADVANCED • LEVEL 3 • NUMERICAL

A 5° crown prism has $n_v = 1.53$, $n_r = 1.51$ and $n_y = 1.52$. It is joined, inverted, to a thin flint prism. The flint has $n_v = 1.68$, $n_r = 1.64$ and $n_y = 1.65$. The flint angle is chosen so that yellow light is not deviated. Find the magnitude of the net angular dispersion, in degrees, rounded off to two decimal places.

Q12 JEE ADVANCED • LEVEL 3 • SINGLE CORRECT

An achromatic pair of focal length +40 cm is made of two lenses in contact. One is crown glass ($\omega = 0.03$), the other flint ($\omega = 0.05$). The focal lengths of the two lenses are:

- (A) crown +16 cm, flint -26.7 cm (B) crown -16 cm, flint +26.7 cm
(C) crown +26.7 cm, flint -16 cm (D) crown -26.7 cm, flint +16 cm

Q13 JEE ADVANCED · LEVEL 3 · SINGLE CORRECT

A 5 cm rod lies along the axis of a concave mirror ($f = 20$ cm). It runs from 25 cm to 30 cm in front of the mirror. How long is its image?

- (A) 35.6 cm (B) 40 cm
(C) 5 cm (D) 80 cm

Q14 JEE ADVANCED · LEVEL 3 · NUMERICAL

A medium fills $0 < y < 1$ m with $n = 2 - y$, y in metres. A ray starts at $y = 0$, moving upward at 60° to the y axis. At what height, in metres, does it travel horizontally? Round off to two decimal places.

Q15 JEE ADVANCED · LEVEL 3 · ONE OR MORE CORRECT

An equiconvex lens ($n = 1.5$, both radii 30 cm) has its back face silvered. Light falls on the front face. Which of the following are correct?

- (A) It acts as a concave mirror of focal length 7.5 cm. (B) An object 15 cm in front gives a real image 15 cm in front.
(C) Its focal length is 15 cm. (D) Glass of higher n would shorten its focal length.

Practice Set: Answers and Traps

Each answer shows the working, then what each wrong option gets wrong. If you chose a wrong option, find your mistake there.

Q1 • (B) 20 cm. A real image is inverted, so $m = -3$ and $v = 3u$. Then $\frac{1}{3u} + \frac{1}{u} = -\frac{1}{15}$, so $u = -20$ cm. **Traps:** (A) is the upright, virtual case, $m = +3$. (C) takes the image distance as $3f$. (D) is v , not u .

Q2 • (C) 5. $360/72 = 5$ is odd, and the object is off the bisector. So there are $360/\theta = 5$ images. **Traps:** (A) uses $360/\theta - 1$, which holds only on the bisector. (B) adds 1 instead. (D) counts only the first two reflections in each mirror.

Q3 • (A) 10 cm. Each layer counts on its own: $\frac{6}{1.5} + \frac{8}{4/3} = 4 + 6$. **Traps:** (B) is the real depth. (C) divides 14 cm by the average index. (D) forgets the oil layer.

Q4 • (D) $\sin^{-1}(8/9)$. At a boundary, $\sin C = \frac{n_{\text{lighter}}}{n_{\text{denser}}} = \frac{4/3}{1.5} = \frac{8}{9}$. **Traps:** (A) is glass to air. (B) is water to air. (C) turns the ratio upside down and gives a sine above 1.

Q5 • (B) -160 cm. Power goes as $(\frac{n}{n_m} - 1)$. In air that is 0.5. In the liquid it is $\frac{1.5}{1.6} - 1 = -0.0625$. So $f = 20 \times \frac{0.5}{-0.0625}$. **Traps:** (A) drops the sign: the lens now diverges. (C) multiplies f by the liquid index. (D) assumes the lens only flips.

Q6 • 40. $\frac{1}{F} = \frac{1}{20} - \frac{1}{20} - \frac{10}{(20)(-20)} = \frac{1}{40}$. **Traps:** Adding the powers gives zero, which ignores the 10 cm gap.

Q7 • (A) 2 cm. $\frac{f_o}{f_e} = 30$ and $f_o + f_e = 62$, so $31f_e = 62$. **Traps:** (B) is the objective. (C) divides 62 by 30 and forgets the eyepiece is part of the length. (D) divides by 32.

Q8 • (C) -2. The intercept is $1/f$, so $f = 20$ cm. Then $\frac{1}{v} = \frac{1}{20} + \frac{1}{-30} = \frac{1}{60}$, $v = 60$ cm, and $m = \frac{v}{u} = \frac{60}{-30}$. **Traps:** (A) drops the sign of the real image. (B) takes u/v . (D) uses the mirror form, $1/v = 1/f - 1/u$.

Q9 • (D) 30 cm. M_1 shows the object 5 cm behind it. M_2 shows it 15 cm behind M_2 , which is 35 cm from M_1 . M_1 then images that 35 cm behind it. **Traps:** (A) doubles the mirror gap. (B) doubles the 5 cm. (C) is the gap itself.

Q10 • (A), (B) and (C). Along the axis the image moves at m^2 times the object's speed. At C, $m = -1$, so the speeds match. Beyond F, the image runs from F out to infinity, away from the mirror. Near F, $|m|$ is huge, so the image is fastest. **Traps:** (D) is false: at the pole $m = 1$, so the image moves as fast as the object. It confuses image distance with image speed.

Q11 • 0.06. No yellow deviation: $0.52 \times 5 = 0.65A_2$, so $A_2 = 4^\circ$. Net spread: $0.02 \times 5 - 0.04 \times 4 = -0.06^\circ$. **Traps:** Stopping at $A_2 = 4.00$ answers a different question.

Q12 · (A). $\frac{0.03}{f_1} + \frac{0.05}{f_2} = 0$ gives $f_2 = -\frac{5}{3}f_1$. Then $\frac{1}{f_1} + \frac{1}{f_2} = \frac{2}{5f_1} = \frac{1}{40}$, so $f_1 = 16$ cm and $f_2 = -26.7$ cm. **Traps:** (B)

flips both signs, but the crown must be convex for a positive total. (C) swaps the two ω values. (D) uses $\omega \times f$ instead of ω / f .

Q13 · (B) 40 cm. Near end, $u = -25$: $\frac{1}{v} = -\frac{1}{20} + \frac{1}{25}$, $v = -100$ cm. Far end, $u = -30$: $v = -60$ cm. Length 40 cm. **Traps:**

(A) uses m^2 at the middle, which fails for a long rod. (C) assumes no stretch. (D) uses $m^2 = 16$ from the near end.

Q14 · 0.27. $n \sin \theta$ is fixed: $2 \sin 60^\circ = \sqrt{3}$. The ray is horizontal when $\sin \theta = 1$, so $n = \sqrt{3} = 1.732$, at $y = 2 - 1.732 = 0.268$ m. **Traps:** Measuring θ from the horizontal gives $2 \cos 60^\circ = 1$. That puts the turn at the very top, $y = 1$ m.

Q15 · (A), (B) and (D). Light crosses the lens twice and reflects once: $P = 2P_L + P_M$. $P_L = 0.5 \times \frac{2}{30} = \frac{1}{30}$ and

$P_M = \frac{2}{30}$. So $P = \frac{4}{30}$ and $f = 7.5$ cm. 15 cm is $2f$, so the image is at 15 cm, real. **Traps:** (C) counts the lens only once. (D) is true; a higher n raises P_L , so f shrinks.

★ Ray Optics • Fact Sheet

Every rule for revision day. Print this page alone.

SIGN RULE

Measure from the surface.

Along the light: +.
Above the axis: +.

PLANE MIRRORS

Images: $\frac{360}{\theta}$ or $\frac{360}{\theta} - 1$

Mirror turns θ , ray turns 2θ .
Two mirrors: $\delta = 360^\circ - 2\theta$.

SPHERICAL MIRRORS

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}, m = -\frac{v}{u}$$

$$f = \frac{R}{2}$$

Concave f is negative.

REFRACTION

$$n_1 \sin i = n_2 \sin r$$

Apparent depth $\frac{d}{n}$.

Slab shift $t(1 - \frac{1}{n})$.

TOTAL REFLECTION

$$\sin C = \frac{1}{n}$$

Dense to light only.
Water 48.6° , glass 41.8° .

CURVED SURFACE

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

One surface at a time.
Image becomes the next object.

LENS MAKER

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

In a liquid use $\frac{n}{n_m} - 1$.

LENSES

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}, m = \frac{v}{u}$$

Gap d: $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$

Newton: $xy = f^2$. Screen:
 $D \geq 4f$.

PRISM

$$\delta = i + e - A, r_1 + r_2 = A$$

Minimum: $i = e, r = \frac{A}{2}$.

Thin: $\delta = (n-1)A$.

DISPERSION

$$\omega = \frac{n_v - n_r}{n_y - 1}$$

No spread: $\omega_1 \delta_1 + \omega_2 \delta_2 = 0$

No bend: $(n_1 - 1)A_1 = (n_2 - 1)A_2$

ACHROMAT

$$\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0$$

Colour blur: $f_r - f_v = \omega f$.
Needs two glasses.

INSTRUMENTS

$$\text{Microscope} \approx \frac{L}{f_o} \cdot \frac{D}{f_e}$$

Telescope $\frac{f_o}{f_e}$, length $f_o + f_e$.

D = 25 cm.

IMAGE SPEED

Mirror $-m^2$, **lens** $+m^2$
times.

Across the axis: m times.
Long rod: image each end.

CHANGING N

$n \sin \theta = \text{constant.}$

Ray curves toward higher n.

Depth: $\int \frac{dy}{n}$.

SILVERED LENS

$$P = 2P_{\text{lens}} + P_{\text{mirror}}$$

Flat side: $f = \frac{R}{2(n-1)}$.

Curved side: $f = \frac{R}{2n}$.



Logic Bloom

Simplest way to understand the NCERT.

`logicbloom.co.in`



★ RAY DIAGRAMS STILL FEEL LIKE GUESSWORK?

Play it. Then practice it.

Open Ray Optics in the Logic Bloom app. Drag objects past mirrors and lenses. Watch the rays redraw and the image flip as you cross F. Free to start.

SCAN → PLAY • READ • PRACTICE