Chapter 12 – Light

Definitions

Phrase	Definition
Reflection	Rebounding of light at surface
Incident ray	Light ray that hits reflecting surface
Reflected ray	Light ray that bounces off reflecting surface
Point of incidence	Point which incident ray hits reflecting surface
Normal	Perpendicular to reflecting surface at point of incidence
Angle of incidence (i)	Angle between incident ray & normal
Angle of reflection (r)	Angle between reflected ray & normal
Refraction	Bending of light when passes from one optical medium to another
Refracted ray	Light ray that enters medium and undergo change of direction
Angle of refraction (r)	Angle between refracted ray & normal
Critical angle	Angle of incidence in optically denser medium where angle of refraction in optically less dense medium is 90° (along boundary)
Total internal reflection	Complete reflection of light ray inside optically denser medium at boundary with optically less dense medium
Principal axis	Horizontal line passing through optical centre of lens
Optical centre (C)	Midpoint between lens surfaces on principal axis
Focal point / principal focus (F)	Point which all parallel rays converge after refraction (2 focal points: 1 on each side of lens)
Focal plane	Plane passes through focal point, perpendicular to principal axis
Focal length (f)	Distance between optical centre & focal point

12.1 Reflection of Light

See objects: only if light from object enters eye

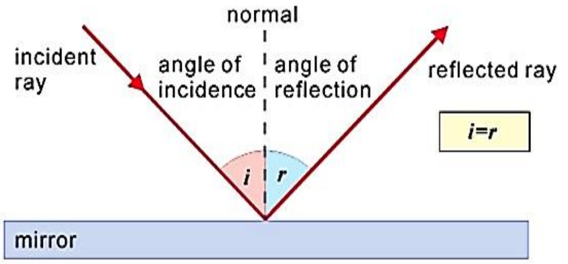
Object	Observation	Examples
1. Luminous	Give out own light	Lamp, fire
2. Non-luminous	Reflect light from light source into eyes	Wall picture

Light rays: represented with straight lines with arrows
→ arrow: direction the light travels

A **light beam** = a bundle of light rays
1. Bundle of parallel rays (distant object)
2. Bundle of convergent rays
3. Bundle of divergent rays (nearby object)

Laws of reflection

Law of reflection	Explanation
First	Lie on same plane 1. incident ray 2. reflected ray 3. normal at point of incidence
Second	angle of incidence = angle of reflection $(i = r)$



Types of reflection

1. **Regular reflection**
2. **Irregular reflection**

All surfaces reflect light

	Regular reflection	Diffuse (irregular) reflection
Surface	Smooth	Rough
Law of reflection (2nd) for each individual ray	True	
Reflection of parallel rays	Same direction (even surface)	Different direction (uneven surface)
Angle of incidence & reflection of all rays	Same	Different
Normal at all points of incidence	Parallel	Not parallel

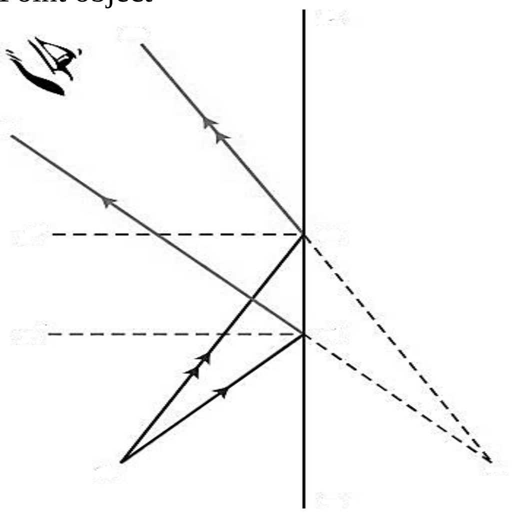
Characteristics of plane mirror image

Characteristics of plane mirror image:

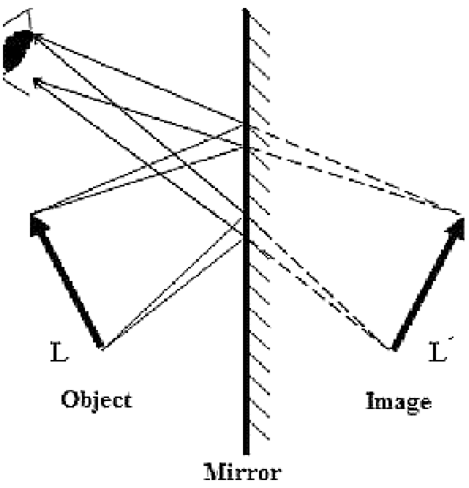
1. **Laterally inverted**
2. **Upright**
3. **Virtual** (not formed by real rays, not formed on a screen)
4. **Same size** as object
5. Object distance = image distance ($\boldsymbol{u} = \boldsymbol{v}$)

Ray diagrams for plane mirrors

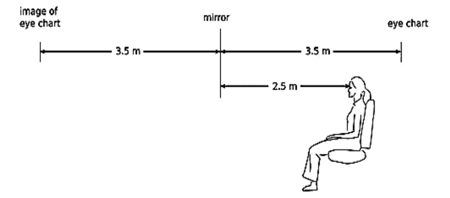
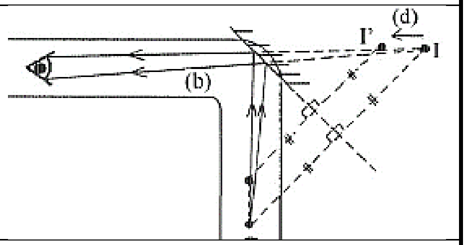
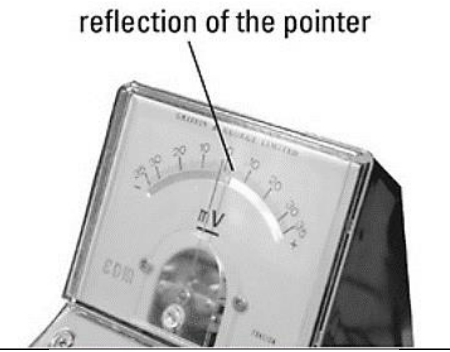
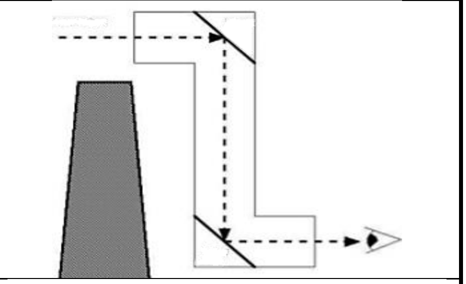
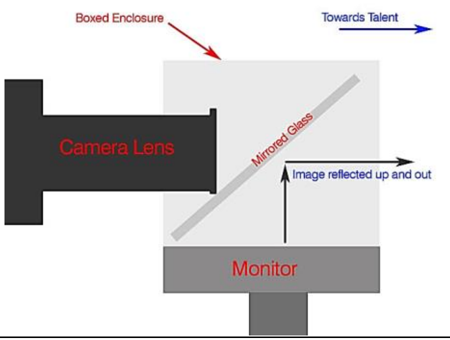
Point object



Extended object



Application of mirrors

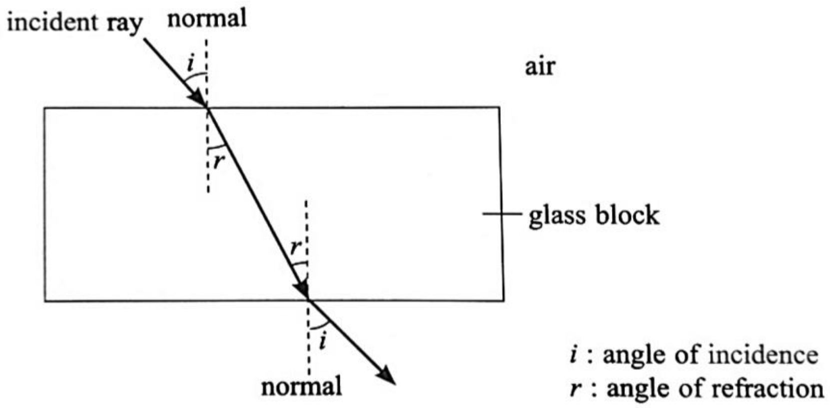
Application	Explanation	Figure
1. **Vision testing**	Carried out in small room • Mirror: make letters on eye chart appear further away • Distance $= u + v$	
2. **Blind corner mirror**	Curved mirror 1) Corner of shops (shoplifter) 2) See around blind corners (driver)	
3. **Instrument scale**	Mirror below pointer (avoid parallax error) → pointer aligned with mirror image	
4. **Periscope**	• 2 plane mirrors: inclined at 45° • Look over obstacles (wall)	
5. **Teleprompter**	• Mounted on camera • Newsreader: read news & maintain eye contact	
6. Other uses	Optical instruments 1) Telescope 2) Overhead projector 3) CD player	

12.2 Refraction of Light

Refraction: bending of light ray as it travels across boundary of two optical media

- Light travels at different speeds from one medium into another
- Light ray bends

Optical medium	Bending
less dense → denser	bend towards normal
denser → less dense	bend away from normal



Laws of refraction

Law of refraction	Explanation
First	Lie on same plane 1. incident ray 2. refracted ray 3. normal
Second	**Snell's law**: $\frac{\sin i}{\sin r} = k$ where k is a constant

Principle of reversibility

- Light ray: travel along same path if direction reversed
- Reflection & refraction

<u>Refractive index and speed of light</u>

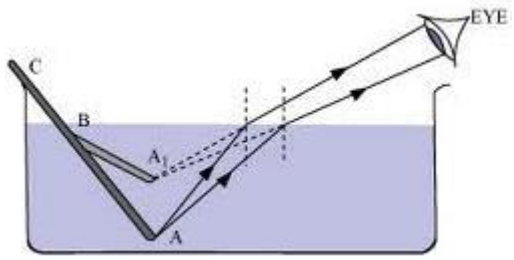
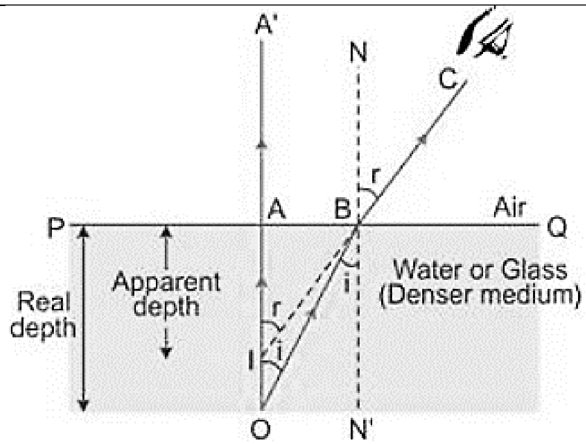
Refractive index (n)

Formulae	Key	The higher the refractive index, …
$\boldsymbol{n = \frac{c}{v}}$	c = speed of light in vacuum (air) v = speed of light in medium	The slower light travels in medium
$\boldsymbol{n = \frac{\sin i}{\sin r}}$	i = angle of incidence in vacuum (air) r = angle of refraction in medium	The smaller the angle of refraction r (more bent towards normal)
$\boldsymbol{n = \frac{d_r}{d_a}}$	d_r = real depth d_a = apparent depth	

Refractive indices of some optical media

Medium	Refractive index
Air	≈ 1.00
Water	1.33
Glass	1.50
Diamond	2.40
Perspex	2.40

Daily phenomena & application of refraction

Phenomena	Explanation	Figure
1. Bent objects	Reflected light from immersed part refracts (water → air)	
2. Misperception of depth	Appear shallower	

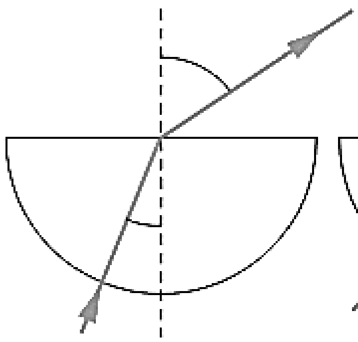
12.3 Total Internal Refraction

Critical angle

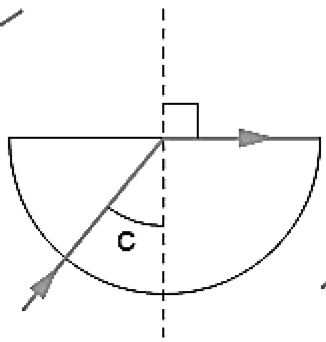
Conditions for total internal refraction:

1. light ray in optically denser medium strikes boundary with optically less dense medium
2. **angle of incidence > critical angle** (optically denser medium) – $i > r$

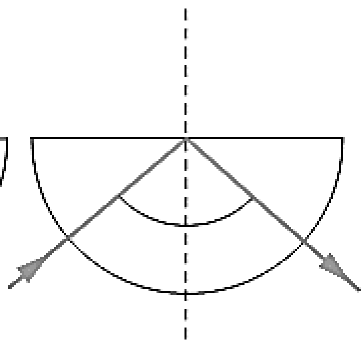
Refraction



Critical angle



Total internal reflection



Formula:

$$\boxed{\sin c = \frac{1}{n}}$$

c = critical angle of optically denser medium
n = refractive index

Proof: by Principle of Reversibility, visualise same light ray travel from air to glass (reverse direction)

$$n = \frac{\sin r}{\sin i} = \frac{\sin 90°}{\sin c} = \frac{1}{\sin c}$$

Application of total internal refraction

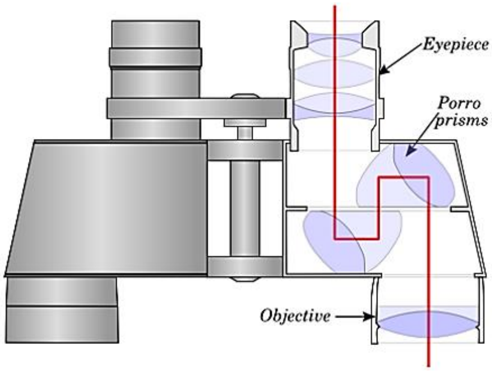
Glass prism

→ better light reflector

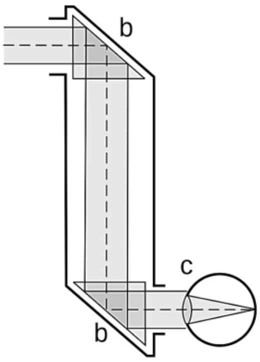
1. × silvered surface (can wear off)
2. × produce multiple reflections
3. Light × absorbed by surface

Application	Explanation
1. **Binoculars**	• Reduce size of binoculars • Rectify inverted image produced by lenses → upright image
2. **Periscopes**	Give clearer images (upright)
3. **Single Lens Reflex (SLR) camera**	Use pentaprism (five-sided prism) 1) Turn light ray round inside camera 2) See actual picture through camera lens

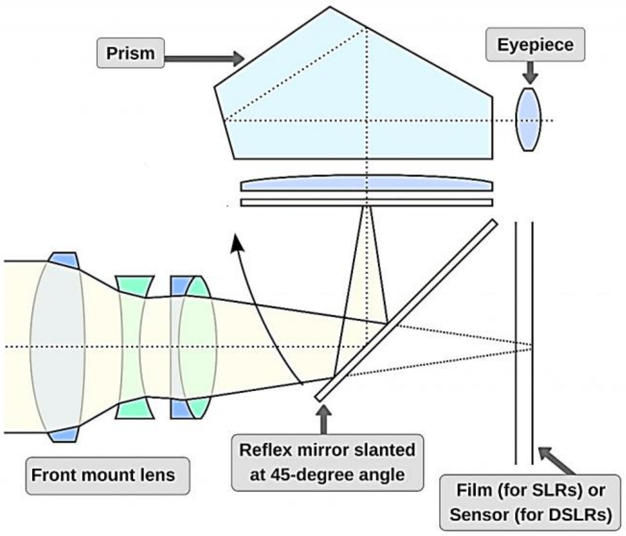
Binoculars



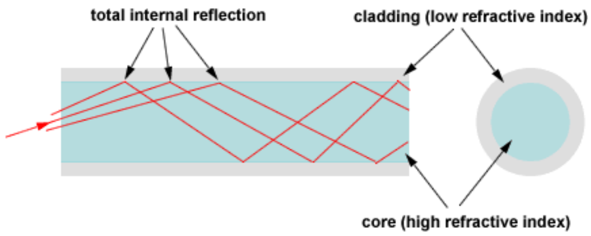
Periscopes



SLR camera



Optical fibre



- Appearance
  1. long, thin
  2. flexible
  3. made of glass / plastic
- Transmit light over long distance → transmit data
- Light ray: internally reflected at boundary between 2 reflective materials

Part	Refractive index
Core	High
Coated material	Low

<table>
<tr><td>Industry</td><td>Explanation</td></tr>
<tr><td>1. Telecommunication</td><td>Comparison with copper wires
<table>
<tr><td>Advantage</td><td>Explanation</td></tr>
<tr><td>1) Higher carrying capacity</td><td>Carry more information over long distance</td></tr>
<tr><td>2) Less signal degradation</td><td>Signal experiences less signal loss</td></tr>
<tr><td>3) Light weight</td><td>Lighter</td></tr>
<tr><td>4) Lower cost</td><td>• Cheaper to manufacture
• × suffer electromagnetic interference (× conduct electricity)</td></tr>
</table></td></tr>
<tr><td>2. Medical</td><td>• High flexibility
• Endoscopes: see inside hollow organs</td></tr>
</table>

12.4 Refraction by Thin Lenses

Lens: piece of glass with curved surface

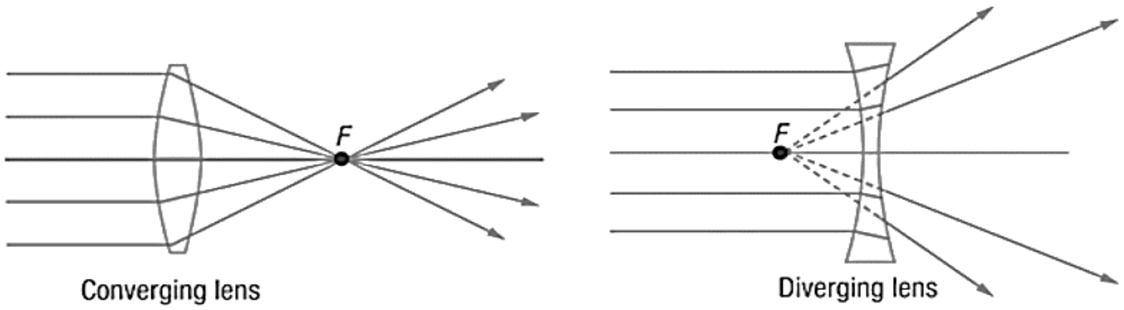
Converging		Diverging	
Lenses	Figure	Lenses	Figure
1. Biconvex		1. Biconcave	
2. Plano-convex		2. Plano-concave	
3. Convex-convex (meniscus)		3. Concave-concave (meniscus)	

Path of light through a lens

Process of refraction

- Surface of lens is curved
- Parallel light rays hitting different parts of its surface have different angles
- Individual rays refract by different angles

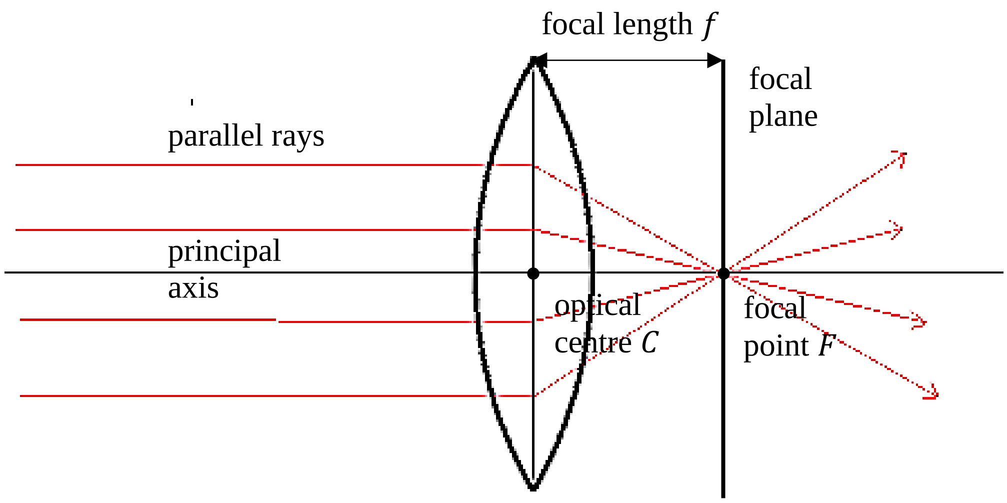
Angle of refraction	Position
Largest	outermost part of lens
No	middle of lens



Converging lens: converge to a point

Lens	Shape	Light rays
Converging lens	Thicker in the centre	Converge to a point
Diverging lens	Thinner in the centre	Diverge from a point

Thin converging lens



12.5 Ray Diagrams for Thin Converging Lenses

Rules for light rays

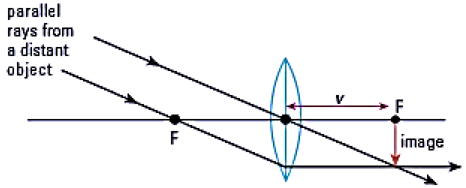
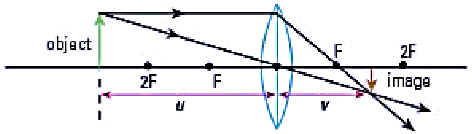
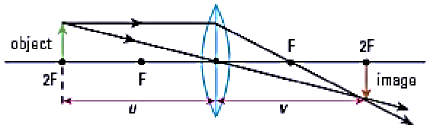
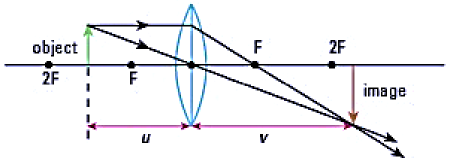
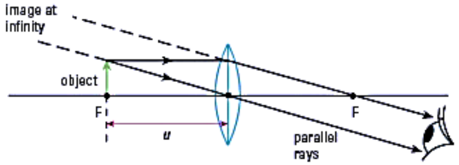
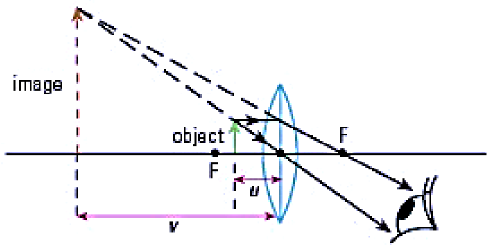
Pass through optical centre	Parallel to principal axis	Pass through focal point
		
× bend (undeviated)	Refracted – pass focal point	Refracted – parallel to principal axis

<u>Position of image by thin converging lens</u>

Drawing ray diagram

Step	Explanation
1. Set up ray diagram	• **Principal axis**: horizontal line • **Converging lens**: double headed arrow, perpendicular to horizontal line • **Optical centre**: intersection of 2 lines • **Focal point**: label on principal axis
2. Place object on left of lens	**Object**: vertical arrow on the left, label it
3. Trace rays, locate image	• Draw **2 rays** from tip of object 1) Pass through <u>optical centre</u> 2) Parallel to <u>principal axis</u> • Real image: intersection point of rays Virtual image: if rays diverge, extend backwards • Draw arrow, label it

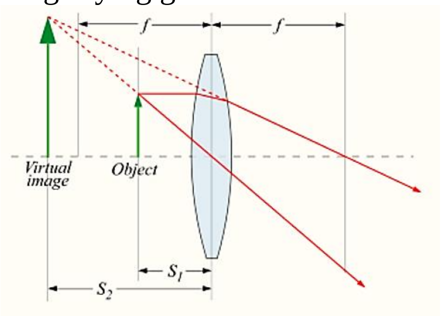
Different distances

<table>
<tr><th>Object distance (u)</th><th>Ray diagram</th><th colspan="3">Type of image</th><th>Image distance (v)</th><th>Side of lens</th><th>Usages</th></tr>
<tr><td>$u = \infty$</td><td>
</td><td rowspan="4">real</td><td rowspan="4">inverted</td><td rowspan="2">diminished</td><td>$v = f$</td><td rowspan="4">opposite</td><td>Object lens of telescope</td></tr>
<tr><td>$u > 2f$</td><td>
</td><td>$f < v < 2f$</td><td>Camera
Eye</td></tr>
<tr><td>$u = 2f$</td><td>
</td><td>same size</td><td>$v = 2f$</td><td>Photocopier making same-sized copy</td></tr>
<tr><td>$f < u < 2f$</td><td>
</td><td rowspan="3">magnified</td><td>$v > 2f$</td><td>Projector
Photograph enlarger</td></tr>
<tr><td>$u = f$</td><td>
</td><td rowspan="2">virtual</td><td rowspan="2">upright</td><td>$v = \infty$</td><td rowspan="2">same</td><td>Eyepiece lens of a telescope</td></tr>
<tr><td>$u < f$</td><td>
</td><td>$v > u$</td><td>Magnifying glass</td></tr>
</table>

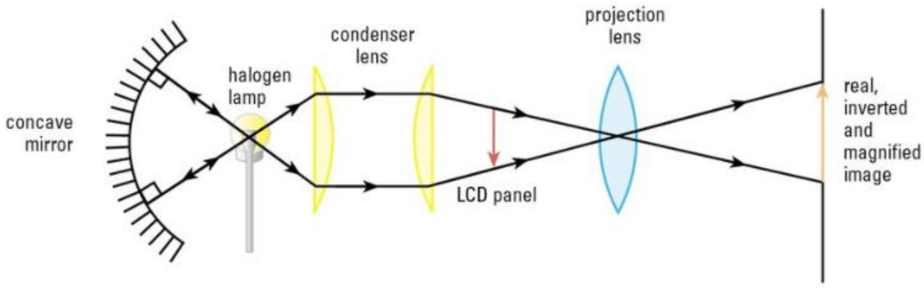
Application of converging lenses

Application	Object distance	Explanation
1. **Magnifying glass**	$u < f$	• Lens: positioned at distance $> f$ • Get magnified image
2. **Liquid Crystal Display (LCD) projector**	$f < u < 2f$	1) Light from **halogen lamp**: reflected by concave mirror onto condenser lenses 2) Light gathered through refraction by **condenser lenses**, directed through LCD panel to projection lens → panel: upside down & between f, $2f$ 3) Light: refracted by **projection lens** Adjust lens forwards and backwards to obtain sharp image on screen 4) Light reaches **screen** → image: real, upright, magnified
3. **Film camera**	Distant object: $d = f$ Nearer object: $d > f$	Vary lens-to-film distance d

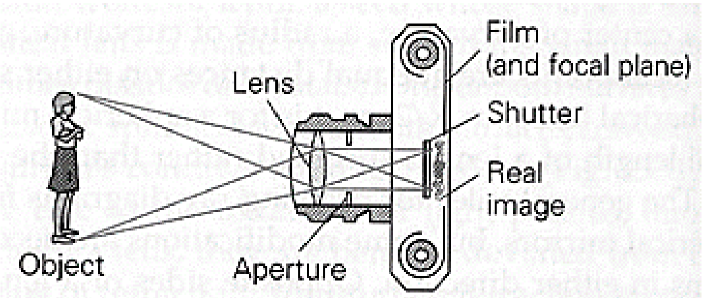
Magnifying glass



LCD projector



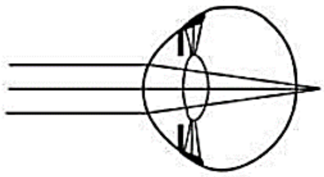
Film camera



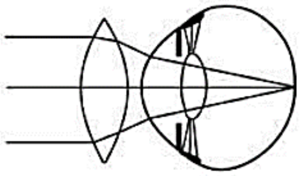
Visual correction

Visual	Problem	Correction
1. **Long-sightedness** (hyperopia)	• Eyeball: shorter than normal • Eye: × focus a clear image of close object on retina	**Converging** lenses • Converge light rays before entering eyes • Converged rays focused on retina → sharp image
2. **Short-sightedness** (myopia)	• Eyeball: longer than normal • Eye: can focus on near objects • parallel light rays (distant object) focused in front of retina → blurred image	**Concave** lenses • Diverge rays (distant objects) before entering eye • Diverged rays focused on retina → sharp image

Long-sightedness

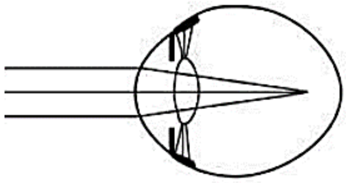


Light focused behind the retina

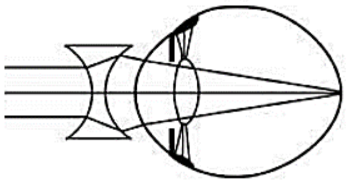


Corrected with convex lens

Short-sightedness



Light focused in front of retina



Corrected with concave lens