Unit 13 · Light

STUDY NOTES

Key terms

Lens: transparent piece with two surfaces, at least one curved, that refracts light.

Convex (converging): thicker in the middle. **Concave (diverging)**: thinner in the middle.

Optical center (O): middle point of the lens; a ray through it goes straight on.

Principal axis: line through O and the centers of curvature of the two faces.

Principal focus (F): where parallel rays meet (convex) or seem to spread from (concave).

Focal length (f): distance from O to F.

Real image: rays really meet; can be caught on a screen. **Virtual image**: rays only seem to come from it; seen only by looking into the lens.

Power: reciprocal of the focal length in meters; unit **diopter** (D).

Magnification (m): height of image ÷ height of object; no unit.

Least distance of distinct vision (D): about 25 cm for a young adult.

Normal adjustment: telescope with the first image at the eyepiece's focus; final image at infinity.

Formulas

$P = \frac{1}{f}$	f in **meters**; convex +, concave − **Use:** power of a lens
$P = P_1 + P_2$	powers in D **Use:** thin lenses in contact
$m = \frac{h_i}{h_o} = \frac{v}{u}$	+ real, inverted; − virtual, upright **Use:** magnification
$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$	real distances +, virtual −; f: convex +, concave − **Use:** lens formula
$M = 1 + \frac{D}{f}$	image at 25 cm ($\frac{D}{f}$ with image at infinity) **Use:** magnifying glass
$M = m_o \times m_e$	$m_o = \frac{v_o}{u_o}$, $m_e = 1 + \frac{D}{f_e}$ **Use:** compound microscope
$M = \frac{f_o}{f_e}$, $L = f_o + f_e$	normal adjustment **Use:** astronomical telescope

Lenses

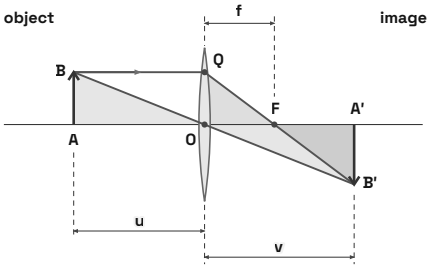
Convex	Concave
biconvex: both faces bulge; hand lens	**biconcave**: both faces curve in
plano-convex: one flat; condenser	**plano-concave**: one flat
concavo-convex: crescent; long sight	**convexo-concave**: crescent; short sight

- spectacles are crescents (menisci), curved like the eye, so the view stays clear as the eye turns
- three rays:
  - **parallel** → through F_2 (or seems to come from F_1, concave)
  - **through O** → straight
  - **through F_1** → leaves parallel
- any two find the image
- more strongly curved → shorter f → greater power; size of P = how strongly, sign = which way
- $f = 20$ cm: $P = 1 \div 0.20 = +5$ D, **not** 0.05 D
- prescriptions: + for long sight, − for short sight; trial lenses add up
- eye: cornea about +43 D, lens about +20 D, together about +60 D (a few mm apart)
- phone: 5–8 thin lenses, act as one of f about 5–7 mm, over +140 D

Lens formula: reading the answer

- work out $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$
- v **positive**: real, far side, inverted; can go on a screen
- v **negative**: virtual, object's side, upright; seen through the lens
- $\frac{1}{v} = 0$: object at F, image at infinity
- m has the same sign as v
- concave: $\frac{1}{v}$ is a sum of two negatives, so always virtual, upright, diminished
- never mix with the "new Cartesian" signs ($\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$); same answers, each with its own signs

Derivation (real image, convex; uses the figure)



1. ABO, A′B′O similar: $\frac{A'B'}{AB} = \frac{v}{u}$

2. OQF, A′B′F similar: $\frac{A'B'}{OQ} = \frac{v-f}{f}$

3. OQ = AB, so $\frac{v}{u} = \frac{v-f}{f} \rightarrow uv = vf + uf$; divide by uvf

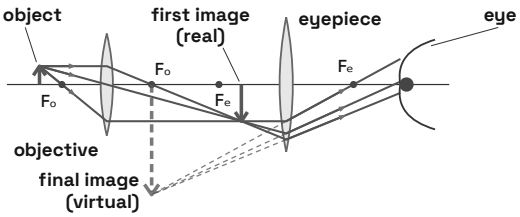
Uses:

- spectacles
- magnifying glasses
- cameras (real, diminished)
- projectors (real, magnified; slide upside down, just beyond F)
- microscopes
- telescopes
- binoculars (two telescopes, prisms)
- peepholes (concave)

Magnifying glass

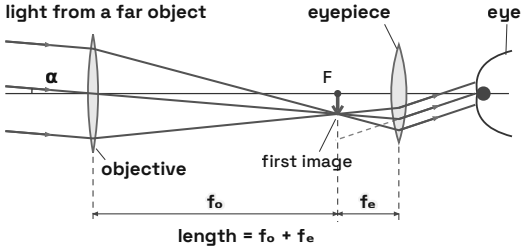
- object just inside F → virtual, upright, magnified, farther away, where the eye can focus
- shorter f → more magnification; $f = 5$ cm gives 6 (image at 25 cm), 5 (at infinity); 10× eyepiece: $f = 2.5$ cm

Compound microscope



- **function**: see very small things close by
- **parts**:
  - objective (very short f, small; 4×, 10×, 40×, 100× on a nosepiece)
  - eyepiece (short f, longer than the objective's)
  - body tube (about 16 cm)
  - stage and clips
  - mirror or lamp with condenser
  - coarse and fine knobs
  - arm
  - base
- object **just beyond Fo** → first image **real, inverted, magnified**, inside Fe → final image **virtual, inverted, magnified**, usually at 25 cm
- 10× and 40×: 400×
- limit: points closer than about half the wavelength (0.2 thousandths of a mm) blur; bacteria yes, most viruses no; over about 1,500× only a bigger blur
- lens distance = $v_o + u_e$

Astronomical telescope



- **function**: see distant objects, by increasing the **angle** at the eye (Moon about ½°; 50× → 25°)
- **parts**:
  - objective (long f, **large**: more light, finer detail)
  - eyepiece (short f, small)
  - sliding tube
- first image **real, inverted, diminished**, at the common focus → final image **inverted, at infinity**
- more magnification: shorter f_e or longer f_o; equal lenses give $M = 1$
- upside down is fine in the sky
- **terrestrial** adds a third lens (longer)
- binoculars prisms
- **Galilean** concave eyepiece, upright, short
- biggest lens telescopes: Yerkes 102 cm; bigger ones are mirrors (Hubble 2.4 m, Webb 6.5 m)

	Microscope	Telescope
object	tiny, close	distant
objective f	very short, small	long, large
first image	real, inverted, **magnified**	real, inverted, **diminished**
final image	virtual, at 25 cm	at infinity
focusing	moves the tube	changes the lens distance
M	$m_o \times m_e$	$\frac{f_o}{f_e}$

COMMON MISTAKES

✗ $P = 1/f$ with f in cm
✓ change to **meters** first.

✗ add focal lengths in contact
✓ add **powers**.

✗ v negative means a mistake
✓ it means **virtual**, on the object's side.

✗ added $\frac{1}{f} + \frac{1}{u}$
✓ $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$.

✗ concave lens with f positive
✓ f is **negative**.

✗ microscope's first image beyond Fe
✓ **inside** Fe.

✗ telescope length $f_o - f_e$
✓ $f_o + f_e$.