

Why do we need microscopes or telescopes?

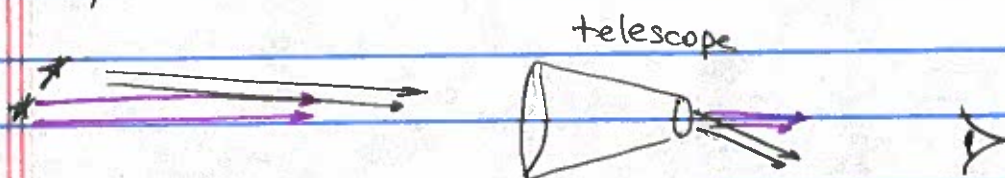
Our eyes or cameras or any other optical receptor has its resolution limit: there are features there is a certain small distance below which we won't be able to resolve any finer structure



If it is smaller than one nerve cell, the brain detects a single dot - no structure

Microscope looks at small objects and magnifies them, making all fine features larger

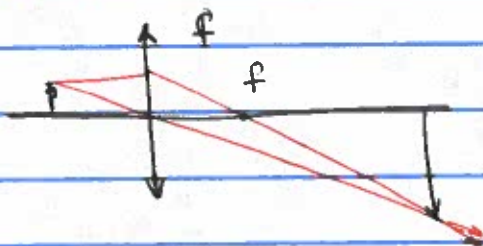
Telescope looks at very large, but very distant objects, so rays from different features arrive almost at identical angles, so telescopes magnify the angles, making rays from different regions bend differently, making angle differences larger, and possible to resolve



Microscopes and telescopes

Microscopes are optical systems for viewing small objects, so we need a large magnification

In principle, a single lens can produce enlarged images



$$0.1'' = 0.004 \text{ in}$$

$$d_i = \frac{d_o \cdot f}{d_o - f}$$

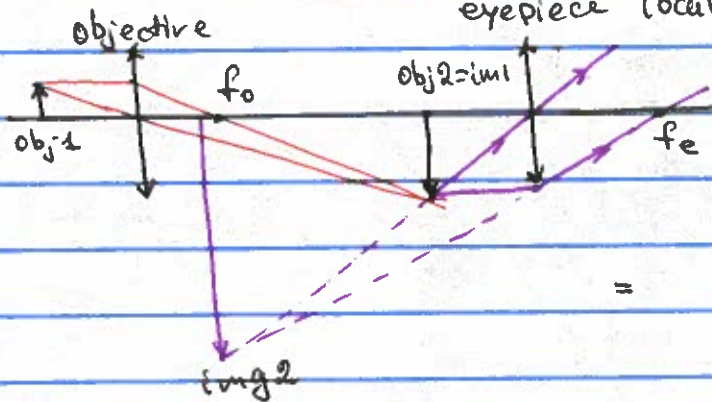
$$m = -\frac{d_i}{d_o} = -\frac{f}{d_o - f}$$

$$\text{if } f = 5 \text{ mm} \quad d = 5.1 \text{ mm}$$

$$m = -\frac{5 \text{ mm}}{0.1 \text{ mm}} = -50$$

close to
max achievable

Instead of a single lens, most microscopes use two lenses: objective and eyepiece (ocular lens)



Total magnification

$$m = m_{\text{objective}} \cdot m_{\text{eyepiece}}$$

$$= \frac{d_{\text{img1}}}{d_{\text{obj1}}} \cdot \frac{d_{\text{img2}}}{d_{\text{img1}}}$$

$$d_{\text{obj1}} \approx f_1$$

$$d_{\text{obj2}} \approx f_2$$

$$d_{\text{img2}} \approx d_{\text{near}} \approx 25 \text{ cm}$$

convenient for eyes

magnification of a microscope

$$M = \frac{d_{\text{img1}} \cdot d_{\text{near}}}{f_{\text{obj}} \cdot f_{\text{eye}}}$$

Confocal microscope allows to select imaged sources from specific depth by placing an aperture and filtering out any light not tightly focused on the aperture

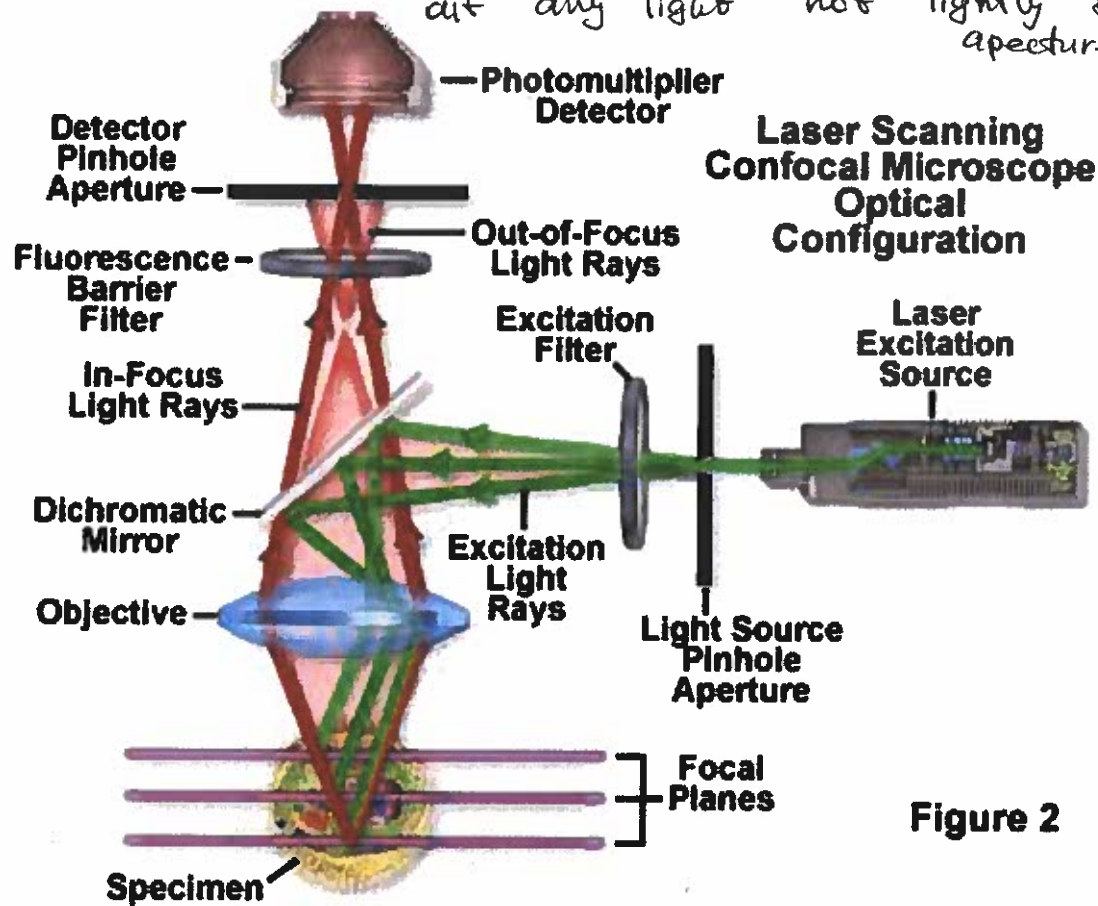


Figure 2

Confocal and Widefield Fluorescence Microscopy

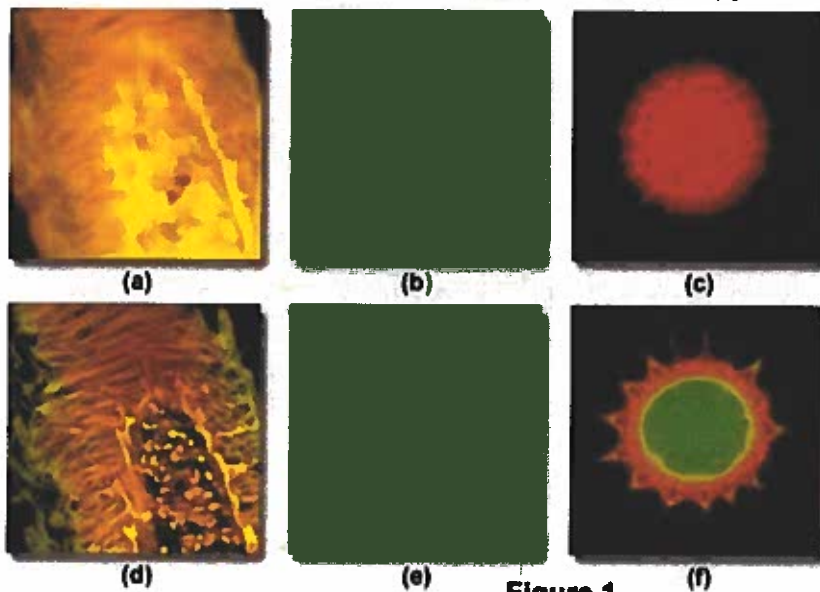
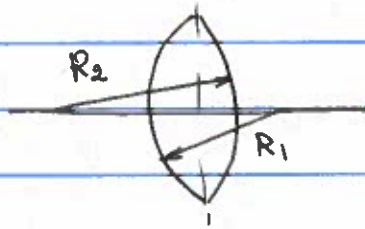


Figure 1

How to make a short focus lens? To make rays bend stronger $\rightarrow$ to have high surface curvature for spherical lenses



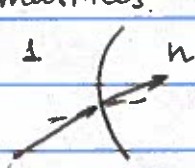
$$\frac{1}{f} = (n-1) \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \quad \text{(double convex lens)}$$

Glass $n = 1.5$ ~~*~~ (for a thin lens)

$$R_1 = R_2 \quad \frac{1}{f} = \frac{1}{R}$$

If we want $f = 5\text{m}$, $R = 5\text{mm}$ (??)
 $\uparrow$
 a part of 1cm-diameter sphere

Aside: we can easily find the lensmaker eqn using matrices:



$$S_{R1} = \begin{pmatrix} 1 & 0 \\ -\frac{n-1}{R_1 n} & \frac{1}{n} \end{pmatrix}$$

$$S_{R2} = \begin{pmatrix} 1 & 0 \\ -\frac{n-1}{R_2} & n \end{pmatrix}$$

$$S_{R2} S_{R1} = \begin{pmatrix} 1 & 0 \\ -\frac{n-1}{R_2} & n \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -\frac{n-1}{R_1 n} & \frac{1}{n} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -\frac{n-1}{R_2} - \frac{n-1}{R_1} & 1 \end{pmatrix}$$

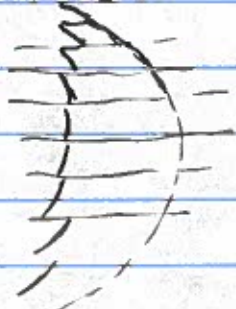
equivalent to $S_f = \begin{pmatrix} 1 & 0 \\ -1/f & 1 \end{pmatrix}$

$$S_{R2} S_{R1} = \begin{pmatrix} 1 & 0 \\ -\frac{n-1}{R_2} & n \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -\frac{n-1}{R_1 n} & \frac{1}{n} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \frac{n-1}{R_2} + \frac{n-1}{R_1} & 1 \end{pmatrix}$$

$-1/f$

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

Fresnel lens



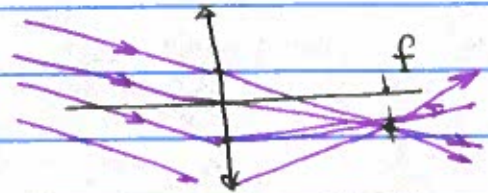
For such lens one removes the bulk (flat piece of glass) and retains the curvature — thinner, lighter lens

Telescope: to make images of very distant objects

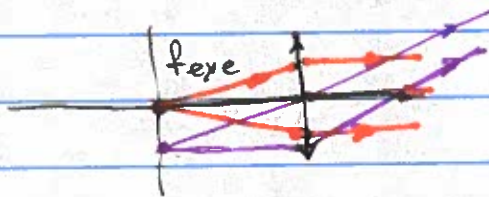
Incoming rays are basically parallel

Again, a telescope has an objective lens and an eye piece.

An objective lens focusses the rays (from infinity) at the focal place of the objective lens

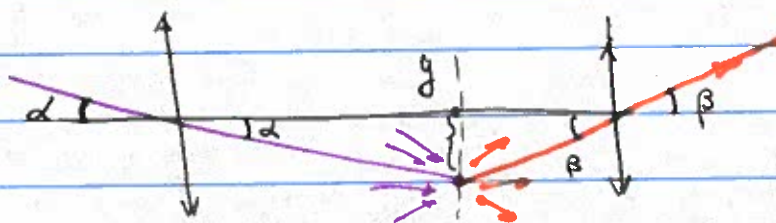


The eye piece is placed such that the magnified image is formed (for camera recording)
 the angle difference b/w two rays from different sources. The focus of an eye piece matches the focus of the objective



After the eye piece two intermediate point sources create

again two families of parallel rays but separated by a larger angle



$$y = f_{obj} \cdot \alpha$$

$$y = f_{eye} \cdot \beta$$

$$f_{obj} \cdot \alpha = f_{eye} \cdot \beta$$

Angular magnification $\frac{\beta}{\alpha} = \frac{f_{obj}}{f_{eye}}$